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DESIGN OF EXPERIMENTS AND EQUIPMENT TO TEST THE BALLOONING CHARACTERISTICS OF CANDU PRESSURE TUBES

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by

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Research report

DESIGN OF EXPERIMENTS AND EQUIPMENT TO TEST THE BALLOONING CHARACTERISTICS OF CANDU PRESSURE TUBES

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ABSTRACT

Experiments have been planned and an apparatus has been designed to enable creep testing of end-of-life pressure tube specimens in a LOCA environment. Effects that could be studied include:

(a) annealing of irradiation damage during transient heating;
(b) effects of hydride blisters on pressure tube ballooning strains; and
(c) effects of uniformly-distributed hydrogen content on pressure tube ballooning strains.

The proposed experimental program will consist of separate effects creep tests on pressure tube sections under transient heating conditions.

RÉSUMÉ

Des expériences ont été prévues et un appareil a été conçu en vue de mener des épreuves de fluage sur des échantillons de tubes de force en fin de vie, dans un contexte d'accident de perte de caloporteur (APC). Les effets possibles à étudier comprennent :

a) le recuit des dommages causés par irradiation pendant le chauffage transitoire;
b) les effets de cloques d'hydrure sur les déformations par gonflement des tubes de force;
c) les effets de la répartition uniforme de la teneur en hydrogène sur les déformations par gonflement des tubes de force.

Le programme d'expériences proposé vise à soumettre des sections de tubes de force à des épreuves de fluage distinctes dans des conditions de chauffage transitoire.

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1. BACKGROUND

A postulated accident scenario for CANDU reactors involves a Loss of Coolant Accident (LOCA) in which the coolant flow through the pressure tubes is reduced, or possibly even stagnates, causing the temperature of the pressure tubes to rise rapidly. In some cases, the combination of pressure and temperature may cause ballooning of the pressure tubes. For the purposes of safety analysis, models have been formulated that describe pressure tube ballooning and failure in terms of high-temperature creep deformation. However, these models are based on the results of tests performed on new pressure tube material in an inert atmosphere, whereas the behaviour of actual pressure tubes may be influenced by in-service degradation and the chemical environment during the accident.

Pressure tubes are subject to neutron irradiation in service. In addition, they absorb deuterium, and the amount absorbed may exceed the solubility limit at operating temperature. Some also may contain hydride blisters due to contact with the calandria tube. These in-service changes are expected to affect the mechanical properties of the pressure tube material. Furthermore, the presence of steam and fission products in the channel, and the annulus gas outside, may also influence the creep properties of the pressure tube material during a LOCA. A literature review (AECB INFO-0351) completed in Phase 1 of this project suggested that insufficient data exist to support use of current models for the analysis of accidents occurring towards the end of service life.

The objective of Phase 2 of this project is to design and plan experiments that will test the potential weaknesses of the existing ballooning model for the case of end-of-life pressure tubes in a LOCA environment, as identified in Phase 1:

(a) Annealing of irradiation damage during transient heating.

(b) Effects of hydride blisters on pressure tube ballooning strains.

(c) Effects of uniformly-distributed hydrogen content on pressure tube ballooning strains.

These experiments, which will be carried out under a subsequent Phase 3, will consist of separate effects creep tests on pressure tube sections under transient heating conditions. Also included in this program is the Work Plan for carrying out Phase 3 that is found in Appendix B of this report.

2. OBJECTIVES

To plan experiments and design experimental equipment (effective and practical from both technical and cost point of view) that will assess the above-identified weaknesses of the existing pressure tube ballooning model and their effect on the predictions of tube failure, contact temperature and time-to-contact under expected conditions of pressure tube irradiation, hydriding and chemical environment.

To prepare a proposal for carrying out Phase 3 work (including budget, work plan and arrangements with subcontractors, if any).

3. TEST SPECIFICATIONS

3.1 General

The two important questions to be answered in the test program are:

(a) What is the effect of changes in material properties or atmosphere on pressure tube strain rate and average strain rate at failure?

(b) How do the changes affect the temperature of the pressure tube at contact with the calandria tube?

The test parameters have been chosen specifically to provide answers to the above questions. The rationale for choice of the various parameters is given below.

3.2 Test Conditions

3.2.1 Temperature Ramp Rate

According to the various safety reports, the conditions at which pressure tubes balloon are:

(a) Small Loss of Coolant without Emergency Coolant Injection: about 1 MPa and <3 K s^{-1} (6 MPa if there is no steam generator cooldown).

(b) Large Loss of Coolant: <6 MPa and <40 K s^{-1}.

(c) Stagnation Feeder Break or Flow Blockage: 10 MPa and 70 K s^{-1}.

(d) Loss of Steam Generators as a Heat Sink (from SDM analysis): >10 MPa and <3 K s^{-1}.

Therefore tests are required at a high and an intermediate pressure with both slow and fast temperature ramps. Tests are also required at low pressure with a slow temperature ramp.

At fast temperature ramp rates, the effects of annealing, hydride dissolution, oxidation and other reactions may lag, resulting in different strain rates than would be inferred from slow ramp rate measurements. The relative rates of these mechanisms and their combined effect on the mechanical properties of the tube material will determine the temperature at contact and the susceptibility of the tube to failure before contact. To determine the maximum combined effect, the experimental matrix must cover a broad range of temperature ramp rates.

A ramp rate of 3 K s^{-1} has been chosen as the lower extreme because results of tests at this ramp rate and comparisons of the results with code predictions are available in the open literature [1], [2], [3]. A rate of 25 K s^{-1} has been chosen for the upper limit; test results at this ramp rate are also available for comparison.

3.2.2 Internal Pressures

Tests to date show that tubes with high internal pressure are prone to failure before contact and that tubes with low internal pressure are likely to have a high temperature at contact. Accordingly, both the high and low pressure conditions must be studied. Further, in tests to date [1], [2], as-received tubes have generally failed at 10 MPa and remained intact below 8 MPa, although circumferential temperature distribution (see 3.2.3 below) was also an important factor in some of the results. It is important to know if that transition in behaviour is altered by a change in material properties or atmosphere. Also, intermediate pressures in the 5 MPa to 7 MPa range are of interest for some accident scenarios. Accordingly, internal pressures of 1, 6 and 10 MPa have been chosen. The low pressures are of interest only at low heating rates; the high pressure, low heating rate condition is included, but it is not considered to be as important as the other conditions and so has been given a lower priority.

3.2.3 Circumferential Temperature Distribution

In tests done to date [1], [2] almost all tubes failed when the temperature variation around the tube was greater than 140 K and the code, GRAD, predicted these results [3]. Accordingly, every precaution has been taken in the design of the equipment, and should be taken during commissioning, to obtain a uniform temperature distribution.

Circumferential temperature distribution is difficult to control regardless of the method of heating. The presence of hydride precipitates, blisters, wall thickness and geometry during ballooning influence local temperatures for both Joule and induction heating. The effect of wall thickness for Joule heating is discussed in Appendix A. Control may be effected by placing a thermal reflector consisting of a thin, polished tube spaced approximately 5 mm from the inner wall of the containment tank at the specimen centre of length. Commissioning tests will determine if this is necessary.

3.2.4 Test Atmospheres

Evidence to date [2] suggests that a steam atmosphere will have no significant effect on either failure before contact or temperature at contact, and it is not anticipated that CO_2 or iodine will have significant effects either although fission product iodine is thought to affect some types of fuel cladding failures. The proposed test matrix is considered sufficient to prove these suppositions.

For the test with CO_2, the specimen will be filled and pressurized with CO_2 to about 5 MPa (the maximum cylinder pressure) and then pressurized with argon.

For tests in a steam atmosphere, the steam will also be used to maintain the internal pressure in the specimen.

The choice of the iodine concentration in the test specimen is based on the following considerations. At end of life each fuel bundle will contain approximately 2 g of iodine [4]. If the content of 12 bundles is released into the approximately 24000 cm^3 of free space in the pressure tube one would have a concentration of about 1.0 mg cm^{-3}. This seems a reasonable choice for the concentration of iodine. Based on evidence [5] that the effect of iodine is ameliorated by the presence of water vapour, steam pressurization will be used with iodine.

3.3. Specimen Treatments

3.3.1 Hydrogen Concentrations

The aim is to test tubes that have been hydrided to levels equal to or exceeding predictions for end of life.

Data presented in current industry reports show that Zr-2.5%Nb pressure tubes in CANDU reactors are picking up deuterium at rates generally less than 2 ppm per year. Such behaviour over twenty years would give up to 40 ppm deuterium ingress or, equivalently, 20 ppm hydrogen. Since the pressure tubes start with up to 20 ppm hydrogen, test specimens hydrided to 40 ppm would be representative of current average predictions.

The maximum deuterium content that has been observed in any Zr-Nb pressure tube is 135 ppm after 12 years. Following the same calculations, 150 ppm hydrogen would be a reasonable "upper bound" concentration. This value is also above terminal solid solubility [6] at operating temperature. Therefore 150 ppm has been selected as the higher concentration for ballooning tests specimens.

Hydriding should be done using the electrolysis method [7] rather than the vacuum annealing method. Electrolysis does not subject the tube to temperatures above about 300°C whereas the vacuum annealing method requires in excess of 900°C to dissolve the oxide layer. Temperatures of this magnitude could affect the metallurgical condition of the tube.

3.3.2 Blister Size and Spacing

Blistered Pickering tubes typically had hydride blisters 2 mm to 8 mm in diameter with an average of about 4 mm, spaced down to 25 mm apart. Since 4 mm is the average blister size, and there is a good deal of information available on growing 4 mm blisters in the laboratory [8], we recommend that 4 mm be chosen as the blister size. Since close spacing is the condition most likely to have an effect on ballooning and rupture, we recommend that the blisters be spaced 30 mm apart. The blisters should span the zone of maximum ballooning.

3.3.3 Irradiated Specimens

It is generally accepted that, at a fluence >1 MeV, radiation damage reaches saturation asymptotically at about 10^{26} n m^{-2}. Tubes should be available from Pickering 4 in 1992 that have been subject to

conditions in excess of these values. It has been agreed with Ontario Hydro (see Appendix C) that specimens suitable for this program, with at least the saturation fluence, can be obtained from the high flux regions of selected tubes.

4. TEST RIG

4.1 General Description

Drawing No. 063B000 shows the general assembly of the test section. It consists of a test specimen supported inside a containment chamber. Electrical bus-bars from a power supply and transformer are attached to electrodes on each end of the specimen. The specimen is directly Joule heated. The power control system provides feedback temperature control for programmed temperature transients. The inside of the specimen is pressurized using argon. An argon purge is maintained outside the specimen. The containment chamber is vented either to atmosphere or to a pressure suppression tank (see Drawing No. 063B020). The rig is designed to be used in a "hot cell" for testing irradiated specimens as well as in a normal mechanical test laboratory.

4.2 Power Supply and Control

Electric power is provided by a single phase, alternating current power supply, equipped with infinitely variable (i.e. stepless) voltage control. The power supply specifications are provided in Table 2. The minimum heating power W_{max} is determined from the maximum design specimen heating rate dT/dt = 30 K s^{-1}, and the mass m and specific heat Cp of the tube specimen:

$$W_{max} = m\, C_p \frac{dT}{dt}$$

Table 1 gives the pertinent dimensions of the test rig and specimen. A specific heat of 0.8 kJ $kg^{-1}K^{-1}$ was used, which is the maximum published value [9] for Zircaloy 4 (data for Zr-2.5%Nb is not available) over the range 300°C to 1200°C, corresponding to the alpha-beta phase transition (800°C to 1000°C). Over the rest of the range, the value is below 0.4 kJ $kg^{-1}K^{-1}$. The specific heat is somewhat affected by hydride dissolution (roughly a 25% increase with 300 ppm hydrogen content), but this effect is at a temperature lower than the phase transition. Therefore the maximum power becomes:

$$W_{max} = (4.0)(0.8)(30)$$
$$= 96\ kW$$

Since not all of the specimen will be at the transition temperature simultaneously, a power supply rating of 100 kW will be sufficient to maintain the maximum heating rate and allow for heat losses and thermal capacity of the electrodes and bus-bars. A lower rating could be used if a lower heating rate through the phase transition were acceptable.

The voltage V is transformed down to match the load resistance R. This is calculated as follows:

$$V = \sqrt{R\,W}$$

where

$$R = \frac{\rho\, A}{L}$$

A resistivity, ρ of 1.8 $\mu\Omega$ m for Zircaloy at 900°C was used to calculate the maximum voltage required (the tube area A and the length L are given in Table 1):

$$V = \sqrt{\frac{(2.1 \times 10^{-6})(0.45)(100000)}{.00137}}$$
$$= 7.7 \text{ volts}$$

and

$$I = \frac{100000}{7.7}$$
$$= 13000 \text{ amps}$$

This design current will be more than adequate over the full temperature range. A remote set-point analog controller provides the control signal for setting and ramping the temperature; the feedback signal is provided by surface mounted thermocouples. The system is illustrated in Figure 1; detailed specifications of the system are given in Table 3.

4.3 Containment Chamber

Drawings 063B004, -006, -010, -013, -014, and -018 specify the containment chamber. The chamber is required for the following purposes:

a) To maintain the required ambient environment.

b) In case of pressure tube rupture, to shield personnel and equipment from blast and possible tube fragments.

c) For tests conducted in a hot cell, to prevent a positive pressure excursion in the hot cell.

The chamber also serves as the structural support for the test specimen and instrumentation. The test specimen is supported horizontally inside the chamber on nickel electrodes that pass through end flanges. The electrode at ground potential is welded to one flange, while the other electrode is electrically isolated from the other flange and free to move axially to allow for thermal and pressure strain. A positive stop is provided to protect against blowout in the unlikely event of a guillotine-type break. A penetration is provided that, for the radioactive specimen tests, is connected to a pressure suppression tank, see Drawing No. 063B020, to reduce the containment chamber pressure loading in the event of tube rupture. Some leakage will occur through the thermocouple, LVDT and electrode penetrations, but these paths will be small such that outflow will be controlled and the hot cell will not become pressurized. For the non-radioactive specimen tests, the chamber is vented to atmosphere. The maximum pressure P_c in the containment chamber/suppression tank immediately following a rupture at pressure P_s is determined from the respective volumes V occupied by the pressurizing medium before and after rupture, i.e.,

$$P_{containment} = P_{specimen} \frac{V_{specimen}}{V_{containment}}$$
$$= \frac{(10000)(.0038)}{(.032) + (.073)}$$
$$= 360 \text{ kPa}$$

This number should be increased by about 20% to account for specimen ballooning prior to rupture. Over a longer period, the pressure increase in a hot cell of the minimum dimensions specified in Section 7 would be about 4 kPa.

4.4 Pressurizing System and Control of Test Environment

The tube pressurizing medium is argon, except for the steam tests. Pressure inside the specimen is regulated with a self-venting pressure regulator connected to an argon cylinder as shown in Figure 1. Provision is made for evacuating the specimen cavity by means of a standard laboratory mechanical vacuum pump; a sample port is provided for introducing measured amounts of water and iodine. The design pressure of the system is 12 MPa; a pressure relief valve is provided.

For the steam tests, pressure will be controlled by setting the temperature controller to maintain the steam pressurizer temperature at saturation for the required pressure.

A slow purge of argon is maintained inside the containment chamber during tests. A pressure switch (see Table 3) is provided to sense the chamber pressure. In the event of specimen rupture, this will immediately trip the power and isolate the pressurizing system.

4.5 Instrumentation

4.5.1 Power

Electric current is measured on the high voltage side of the transformer with a current transformer. Since this measurement is not critical, the additional cost of measuring the secondary current is not considered to be justified. Power is measured with a watt transducer, using the current signal and voltage taps.

4.5.2 Pressure

Pressure inside the specimen is measured with a capacitance-type transmitter (see Table 3). It is connected to a digital process module complete with amplified analog output and display.

4.5.3 Strain

The total circumferential strain is measured using two linear variable differential transformer (LVDT) systems (see Table 3) as shown in the instrumentation assembly Drawing 063B019 and detail Drawing 063B017. Each system incorporates a quartz fibre that is anchored to the top of the containment chamber on a vertical tangent to the specimen OD, wrapped completely around the pressure tube specimen and attached to the armature of an LVDT mounted near the bottom of the tank[1]. This method has been used successfully by Ho [10]. Tensioning of the fibre is achieved by adding a weight to the armature of the LVDT. The fibre is lubricated with graphite to ensure smooth operation. The devices are located 30 mm on either side of the tube mid-point. Adjustments to the armature position can be made from the top after installation of the specimen.

The LVDTs are connected to process modules similar to the pressure coupler, except that they include relay outputs to trip the power, isolate the pressurizing system and vent the specimen when the circumferential strain reaches 19±1%.

4.5.4 Temperature

Based on discussions with representatives of the Atomic Energy Control Board, twenty-four thermocouple probes at 15° intervals are used to monitor the temperature around the specimen at the mid-plane position. This ensures that the temperature distribution at the plane of strain measurement can be adequately specified for code calculations. The probes incorporate 1.5 mm diameter, Type K, Chromel-Alumel, sheathed, ungrounded thermocouples (see Table 3) with an operating range to 1250°C. Instrumentation assembly Drawing 063B019 and detail Drawing 063B015 show the thermocouple

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[1]See section 4.3 for installation procedure.

positions and details of a typical probe assembly, respectively. Each thermocouple is supported within an alumina tube extending into a guide tube attached to the chamber. The sheath of the thermocouple is broken at this location and a stainless steel tube is used for supporting the remaining length. The break is required since the sheath is at the potential of the specimen at the contact position. The ends of the support tubes are fixed with set screws to a larger tube which slides inside the guide tube. A captive spring holds the assembly against the specimen. To provide the small thermocouple junction necessary for fast response the OD is swaged to 0.5 mm diameter at the junction and is bent 90° such that the contact with the specimen is on the cylindrical portion, and the spring force is applied through the alumina tube.

The thermocouples are connected to ice-point compensation process modules with amplified analog output, display, and relay trip outputs. The trips will be actuated to instantly cut off the heating power when any one of the thermocouples reaches 1200°C. Due to the high thermal conductivity of the pressure tube material, the stored heat above 1200°C will be small, and the temperature overshoot is expected to be minimal.

4.6 Data Acquisition and Control

The data acquisition system will acquire and store the temperature, pressure and strain signals prior to and during the transient, for subsequent reduction to engineering units, tabulation and plotting. This requires data storage capacity of at least 1 MB for up to 300 s of data recorded at a minimum 10 Hz sampling rate for each of 32 channels, plus video monitor(s), graphics printer and a digital-to-analog output device. Low-pass filtering of instrument signals, made necessary by the high electrical fields expected near the rig, is provided in the coupling modules. Because of the number of channels required and the sampling speed (10 Hz per channel minimum), a minicomputer based data acquisition system is recommended.

For the hot cell tests with the irradiated specimens, the signals will be recorded using an FM tape recorder and played back into the minicomputer system at the other test location. If the two locations are close enough, all data can be acquired with the main system.

To provide a linear specimen temperature ramp, a voltage ramp is generated by the computer and sent to the controller through a digital-to-analog output device. (Because of speed and other limitations, using available digital programmers would result in a coarse 'staircase' of about 5 K increments for the highest ramp rate and 2 K to 3 K increments for the lowest ramp rate.) Prior to the hot cell tests, the two voltage ramps required for these tests will be recorded on one channel of the tape recorder, and the appropriate ramp will be played back to the controller during the test.

4.7 Hot Cell Facility Requirements

The irradiated specimen tests must be carried out in a licensed hot cell. This facility must measure at least 2 m x 1.5 m x 3 m high and have at least 100 kW of electrical power at 480 V or 600 V single phase available for the power supply. It must be equipped with suitable penetrations for electrical cable and instrument lines, and have facilities for handling the shipping flasks containing the irradiated specimens. Manipulators and skilled workers will be required to install the specimens in the rig and make the final flange and electrical bus connections, and to remove and inspect specimens after testing. The cell must have an adequate filtered ventilation system to accommodate the release of argon without exceeding the maximum permissible pressure in the cell, and to retain possible radioactive particles following a specimen rupture. Information regarding Canadian hot cell facilities is given in Appendix D.

5. TEST SPECIMENS

5.1 Material Specification and Treatment

All specimens are fabricated from 0.45 m long, Zr 2.5%Nb pressure tube material. A total length of 30 m of tubing is required to provide fifty specimens, 0.45 m long, plus ten spares, with a generous allowance for metallurgical samples and cutting.

The irradiated specimens are fabricated from Zr-2.5%Nb pressure tube material irradiated at a fluence greater than 1 MeV to above 10^{26} n m^{-2} (e.g., tubes removed from Pickering 3 or 4 in 1984/85). A length of 4 m is required to yield six specimens, two spares and sufficient metallurgical samples. The tubing should be taken from the centre portion of a pressure tube where the flux is highest and most uniform. If the schedules can be arranged to mesh with Pickering 4 retubing (see Appendix C), the tubes will be rough cut in 0.5 m lengths and shipped to a suitable hot cell facility for final cutting, weld preparation, welding, inspection and testing.

Sixteen as-received specimens will be uniformly hydrided to 40 ppm and sixteen to 150 ppm. Half of each of these will be subsequently blistered. This will provide six test pieces and two spares with each treatment. The hydriding should be done electrolytically [7] to avoid the need to take the temperature into the range where material property changes could occur. Blistering can be achieved by impinging cold air jets onto the outside surface of an internally heated, hydrided tube [8]. The recommended blister size is 4 mm, spaced at 30 mm intervals along the centre 2/3 of the tube length (10 blisters). Because of the time required to grow the blisters (up to 120 days), the hydriding and blister growing should be started early in the program.

5.2 Surface Preparation

The tube surfaces shall be prepared after machining and prior to welding. We recommend that the un-irradiated pressure tube specimens be handled only with gloves during the following final steps before welding to the titanium end caps:

(a) Wash specimens thoroughly with isopropyl alcohol and rinse with as received alcohol.

(b) Autoclave un-irradiated specimens for 24 hours in steam at 400°C at atmospheric pressure.

(c) Remove oxide layer and all other contaminants from weld preparations, using new abrasive paper and "lint free" cloth.

5.3 Specimen Fabrication

Drawings 063B001, -009, and -012 show the test specimen geometry and fabrication details. Pressure tube material will be cut to 0.45 m lengths. Ring samples will be cut from all tubes adjacent to each specimen and archived. Titanium end caps are to be attached by welding (in a hot cell for irradiated specimens). These welds must be full penetration welds, and the welding process must be qualified by destructive examination of sample welds, which should be completed before any specimens are welded. Final machining of the end caps will be carried out after preparation of the pressure tube sections such that a good fit is obtained. This is especially important for the irradiated tubes, which probably have sustained some creep deformation.

The outer weld surfaces of all specimens will be inspected using a standard dye penetrant procedure. For the irradiated specimens, the visual inspection for dye penetration will be carried out using a through-the-wall stereo microscope.

5.4 Specimen Installation & Removal Procedure

The specimen will be installed in the containment chamber as follows, ready for testing to commence. Specimen removal takes place in the reverse order, with actions reversed. The procedure applies to both the unirradiated and irradiated specimen tests. It is assumed that the containment chamber (assembly Drawing No. 063B000, Items 1, 3, 8 & 20) is assembled on its stand and ready to receive the test specimen, with pressure suppression tank (Drawing No. 063B020), instrumentation sense lines, bus-work (excepting final supply voltage bus connection) and pressurization line connected. Depending on the availability of provisions for handling pressure tube specimens in the hot cell, special cradles (see drawing No. 063B022) may be required to support the supply electrode and test specimen. An inspection station is required for the latter (see Section 4).

For the purposes of this procedure it is assumed that the cell is sufficiently decontaminated to provide safe working conditions for about 1 hour. The containment chamber will be equipped with quick-connects for all connections and, if necessary, can be removed from the cell after decontamination, for preparation for the next test. It is further assumed that the cell is equipped only with a crane and a manipulator, and no special jigs, fixtures and handling devices for pressure tubes are available. The cradles, inspection equipment and the specimen, in its shipping container are placed in the hot cell within reach of the hoist and manipulators prior to starting.

(a) Install new quartz fibres (Drawing No. 063B019) without tensioning them, providing ample clearance for the guide tube (Drawing No. 063B016). For the irradiated specimen tests, the fibres will be similarly installed by hand, after the cell has been decontaminated.

(b) Install specimen guide tube, with support pads last, nesting the leading end of the guide tube securely over inboard cylindrical surface of the ground potential electrode (item 8) and resting support pads in bore of flange (item 3). Great care must be taken during this step not to disturb the quartz fibres. The guide tube is shown installed in the containment chamber in Drawing No. 063B023.

(c) Install twenty-four (24) new or rebuilt thermocouple assemblies (Drawing No. 063B019, item 3) over the guide tube.

(d) Insert six (6) bolts, item 19, fully into ground potential electrode (item 8) and withdraw approximately 1 in.

(e) Place supply electrode (item 7) in its special cradle, and store it and insulating flange (item 12) with lifting lug (item 25) at twelve o'clock, within reach of hoist.

For tests with unirradiated specimens, many of the subsequent steps can be performed manually; for irradiated specimen tests, they will be performed remotely, as described below.

(f) Open specimen shipping container, raise test specimen out of container and place horizontally in special cradle provided. Attach hoist to cradle, placing two slings under the channel, and move specimen and cradle to the examination station. Perform specimen examination procedures as described in Section 5.5. Remove specimen and replace in cradle.

(g) Place seal ring (item 14) over spigot at open end of specimen and push to rest against shoulder. Insert six (6) studs (item 18) into threaded holes in closed end of specimen, and turn clockwise until only one thread is showing.

(h) Attach hoist to cradle and position in line with specimen guide tube. Push specimen assembly fully into guide tube and remove and store special cradle.

(i) Rotate test specimen until locating pin (item 17) engages. Fully insert bolts, item 19, and gradually tighten in turn to a torque of 90 to 100 N m.

(j) Perform leak test as follows: Carefully pressurize test specimen to 1 MPa and close isolating valve. Observe specimen pressure for 5 minutes. If pressure falls by more than 10 kPa, depressurize and tighten bolts, item 19, to 120 to 130 N m and repeat leak test. If pressure still falls by more than 10 kPa, unscrew bolts, item 19, and withdraw the specimen into the cradle by reversing steps g) and h), making sure not to withdraw the guide tube. Replace the seal ring (item 14) and repeat steps g) to i). When seal holds pressure adequately, *slowly* withdraw the guide tube.

(k) Attach hoist to cradle containing supply electrode (item 7) and line up with studs (item 18) attached to specimen, making sure that the blow-out protection ring is located inboard. Slide supply electrode (item 7) over studs until it butts against specimen.

(l) Pick up insulating flange and sleeve subassembly (item 12) and slip over test specimen, then adjust until holes line up with studs in containment chamber end flange (item 3) and push into contact with flange. Attach nuts (item 15) to studs and tighten gradually, in turn, to a torque of 90 to 100 N m.

(m) Attach hoist to lifting eye on flexible bus (item 13) and raise bus to vertical, making sure that the six studs (item 18) enter the holes provided in the bus. Attach six (6) nuts to studs and gradually tighten in turn to a torque of 90 to 100 N m.

(n) Tension two (2) quartz fibres by releasing weight on LVDT armatures.

5.5 Specimen Examination Procedures

The object is to measure the local strain at the location of the thermocouples. Measurements of specimen diameter, circumference, and wall thickness will be made before and after testing, using an indexing head on a surface plate to simplify measurements at 15° increments (i.e., the thermocouple spacing), and magnetic bases (e.g., Starrett No. 657A) for attachment (to the surface plate) of the following:

(a) An ultrasonic gauge for the wall thickness measurements.

(b) A shaft encoder with a wheel to ride over the specimen OD as it is rotated, for circumferential measurements.

(c) A guided centre-punch with a controlled impact, capable of marking the tube OD every 15° at the mid-point, such that local strain measurements of highly ballooned or ruptured specimens can be made (see Figure 2 for conceptual sketch). The marks must be such that the strength of the tube is not affected.

All items except (c) above are standard laboratory equipment. Ultrasonic measurements may prove difficult on highly deformed specimens, and it may be preferable to cut the tubes and measure the wall with a micrometer after completing the other examinations.

Photographs will be taken after testing and the specimens will be carefully packaged and stored at a licensed facility such that further measurements and analyses, e.g., the determination of the extent of annealing of irradiation damage or dissolution of zirconium hydride platelets, can be made if and when required.

6 EXPERIMENTAL PROGRAM

6.1 Test Matrix

The test matrix is given in Table 4. The tests are in ten groups, including reference and confirmatory tests and tests with a particular tube treatment (hydrided, blistered, steam environment, irradiated, etc.) The recommended order of testing is as given. Initially, three tests will be carried out with as-received material to confirm reproducibility of previous results. Next, four reference tests will be carried out. The parametric tests will follow, in the order of importance, or as decreed by scheduling considerations (blistered tube tests near the end to give time to grow blisters, irradiated tube tests carried out last due to possible rig contamination). The explanation for the test sequence is given in the comments column and footnotes in Table 4.

Each group of parametric tests consists of five tests comprising two ramp rates and three pressures. To be more cost effective, not all matrix points will necessarily be tested. Within each group of tests a scoping test is chosen to do first at the intermediate pressure and the ramp rate that is considered to be the most severe for the treatment. If this test results in tube rupture, the high pressure test will certainly result in rupture as well, and therefore is not considered worthwhile, and so the low pressure test is carried out next (or, for the 25 K s^{-1} heating rate, the other heating rate is tested). If the intermediate pressure test does not result in rupture, the high pressure test follows. Still, the low pressure test may be important with regards to ballooning, and the decision to omit it must be based on the significance of the effects of the treatment or environment. The intermediate pressure test at the other ramp rate will then be carried out and the same logic will be used to determine which of the other tests in the group are omitted. Other decisions will be made that may further reduce the number of tests, e.g., if the results of the 150 ppm uniformly hydrided specimens or the 150 ppm hydrided blistered specimen tests are not significantly different from the as-received material tests, the 40 ppm hydrided tests could be omitted.

Before any irradiated specimens are tested, four tests will be carried out in the hot cell with as-received material to check the equipment. In the choice of the sequence of irradiated tests, the need to minimize hot cell cleanup between tests, i.e., to carry out the tests least likely to result in rupture first, played a significant part.

6.2 Test Procedures - Non-Irradiated Specimens

After specimen installation is completed, the containment chamber will be purged thoroughly with argon for at least twelve hours at a rate of not less than 20 $cm^3 s^{-1}$. With the containment chamber purge continuing, the specimen will be evacuated and heated to 200°C, followed by back-filling and pressurizing to 1 MPa with argon at least three times.

For the tests with CO_2, before pressurizing with argon the final time, the specimen will be filled and pressurized with CO_2 to about 5 MPa (the maximum cylinder pressure). The argon supply will then be valved in and the specimen pressurized further with argon (or vented for the 1 MPa tests).
For tests with a steam atmosphere (No. 5 and No. 7 on Table 4) the argon supply will be disconnected, leaving the pressure relief valve in place, and the Steam Pressurizer, Drawing No. 063D024, will be connected instead. The pressurizer and connecting tubing will be covered with fiberglass blanket thermal insulation. The pressurizer and specimen will be evacuated, heated to 200°C to de-gas them, and the pressurizer will be filled with 1.5 L of de-ionized water.

For atmospheres with steam and iodine, after de-gassing as above and with the system evacuated, 3.8 g of iodine will be introduced through the sample port. The pressurizer will then be filled with 1.5 L of water and raised to the saturation temperature for the required pressure. The containment chamber will continue to be purged with argon.

The specimen will be heated to 300°C and allowed to equilibrate while instruments and control systems are checked out. The highest or most representative thermocouple(s) will be connected to the power controller. The trips will be armed and the data acquisition system started. Temperature ramping will be initiated and will continue until one of the conditions given below is reached:

(a) 1200°C tube temperature.
(b) 19% circumferential strain.
(c) Specimen rupture.

The pressure tube is theoretically in contact with the calandria tube over the full perimeter at 18% circumferential strain. Terminating the test after this point will preserve information regarding uniformity of strain etc., while limiting damage to thermocouples and supports. The instrumentation process modules will automatically trip the power, isolate the pressurization system and, for the first two above conditions, vent the specimen. After the test is terminated, temperature and strain data versus time will be tabulated and plotted by computer.

6.3 Test Procedures - Irradiated Specimens

Testing is carried out as for the non-irradiated specimen tests, except for the use of the tape recorder in place of the computer data acquisition system, and a function generator temperature ramp input. For the latter, the control voltage ramps could be pre-recorded onto one channel of the tape recorder, and played back during the test while recording the other signals.

7 REFERENCES

[1] R.S.W. Shewfelt and D.P. Godin, "Verification Tests for GRAD, A Computer Program to Predict the Non-Uniform Deformation and Failure of Zr-2.5 wt% Nb Pressure Tubes During a Postulated Loss of Coolant Accident," AECL-8384, March 1985.

[2] E.T.C. Ho and M.J. McGraw, "Transient Deformation Behaviour Of Production Zr-2.5 wt% Nb Pressure Tube Material," Ontario Hydro Research Division Report 81-163K, 1981.

[3] R.S.W. Shewfelt, "Failure Maps For Internally Pressurized Zr-2.5%Nb Pressure Tubes With Circumferential Temperature Variations," AECL 8399, January 1986.

[4] D.M. Wuschke et. al., "Second Interim Assessment Of The Canadian Concept For Nuclear Fuel Waste Disposal," AECL 8373-4, Volume 4 - Post-Closure Assessment, September 1985.

[5] B. Cox, "Pellet Clad Interaction of Zirconium Alloy Fuel Cladding," Journal of Nuclear Materials, Pages 249-292, Vol. 172, 1990.

[6] R. Dutton, "Basic Parameters In Delayed Hydride Cracking," Proceedings Of The Fuel Channel Technology Seminar, Oakville, Ontario, November 1985.

[7] A. Sawatsky, "Hydriding Zircaloy-2 By Electrolysis." AECL 1046, June 1960.

[8] M. Leger and T.P. Byrne, "Hydride Blister Growth In Zr-2.5% wt of Nb Pressure Tube Material," Proceedings Of The Twelfth Annual CNS Symposium On Simulation Of Reactor Dynamics And Plant Control, April, 1986.

[9] EG&G Idaho, Inc, "Matpro - Version 09, A Handbook of Material Properties For Use In The Analysis of Light Water Reactor Fuel Rod Behaviour," Idaho National Engineering Laboratory Report TREE-Nureg-1005, December 1976.

[10] E.T.C. Ho and A. Donner, "A Test Facility For Deformation Of Pressure Tube Samples Under Internal Pressure and Ramp Temperature Conditions In Controlled Environments," Ontario Hydro Research Division Report 83-18K, February 1983.

TABLE 1

PERTINENT DIMENSIONS OF THE TEST RIG AND SPECIMENS

PRESSURE TUBE SPECIMEN DIMENSIONS:	
Tube OD (m)	0.1115
Tube ID (m)	0.1034
Cross Sectional Metal Area (m2)	0.00137
Tube Length (m)	0.45
Tube Mass (kg)	4.0
Tube Inside Volume (m3)	0.0038
CONTAINMENT CHAMBER VOLUME (m3)	0.032
PRESSURE SUPPRESSSION TANK VOLUME (m3)	0.073
MINIMUM REQ'D HOT CELL VOLUME (m3)	9

TABLE 2

100 KVA CONTROLLED POWER SUPPLY SPECIFICATIONS

Type:	Single phase, alternating current, resistance heating power supply. Floating output via dual winding transformer. Full converter AC power controller. External PID controller.
Output Voltage:	0 to 7.7 VAC, 1Ø, 60 Hz
Output Power:	100 kVA (nominal)
Output Current:	13,000 A Max. @ 7.7 VAC
Inputs Required:	600 VAC, 1Ø, 60 Hz, 200 A service, user supplied safety switch and cabling. Transformer primary tapped at 2.5% & 5% FCAN and 2.5% & 5% FCBN for line voltage compensation. 120 VAC, 1Ø, 60 Hz, 15 A maximum.
Protection:	Circuit breaker with adjustable trip current setting. Internal fuse. Adjustable (0 to 140% rated) output current limiter.
Metering:	Power, potential and current accuracy ±1.0 % F.S.
Controls:	Main power 'Start' and 'Stop' pushbuttons. Instrument power 'On/Off'. Current limiter control potentiometer. External PID controller 'Display', 'Mode', 'Setpoint', 'Tuning' and 'Local/Remote' setpoint controls.
Indicators:	Main power 'Available' indicator. Instrument power 'Available' indicator. 'Run' indicator.
Displays:	Process variable display. Controller 'Percent Output', 'Setpoint' and 'Deviation'. Controller tuning constants.
Data Outputs:	0 to 10 VDC analog signals representing temperature, output power, potential and current.
Control Variable:	Pressure tube specimen temperature from external Type 'K' thermocouple via external compensation.
Control Function:	User selectable manual, automatic with local setpoint or automatic with ramped setpoint. Full proportional control with reset and rate action.
Ramp Profile:	From external source. Hold pressure tube specimen at 300° C, ramp specimen from 300° C to 1250° C at rate of either 3° K s^{-1} or 25° K^{-1}.

TABLE 3

INSTRUMENTATION SPECIFICATIONS

ITEM	NO REQ'D	DESCRIPTION
Thermocouples	50 (includes 26 spares)	Premium grade, 1.5 mm dia, Type K, Inconel sheathed, ungrounded c/w tip swaged to .5 mm and bent 90°.
Amplifier/Display/ T/C compensation	24	Thermocouple process monitor, Range: 0 - 1250°C, Type K Accuracy: 0.5°C, 4-1/2 digit display, filtered, Analog output: 0 - 10V, relay output.
LVDT	2	Range: 100 mm min, Output: 4 mVDC/V/mm, Linearity: 1% Operating temperature range: 0° - 80°.
Pressure transmitter	1	Range: 1 - 12 MPa, Accuracy: .5% FS, Output: 0 - 10 VDC.
Amplifier (for LVDT and pressure trans.)	3	Process monitor, Analog output range: 0 - 10V, Accuracy: 0.5°C, 4-1/2 digit display, filtered, relay output.
Pressure switch	1	Mercury switch, 10 - 350 kPa.

TABLE 4

RECOMMENDED TEST MATRIX

TUBE TREATMENT	ATMOSPHERE	SCOPING OR REF. TESTS[1] TEMP. RAMP RATE (K/s)	SCOPING OR REF. TESTS[1] INTERNAL PRESSURE (MPa)	OTHER TESTS (if required) TEMP. RAMP RATE (K/s)	OTHER TESTS (if required) INTERNAL PRESSURE (MPa)	COMMENTS
--- IN TEST LABORATORY ---						
1. AS RECEIVED (Confirmatory Tests)	Argon	3	6.2, 10			- Confirmatory tests to compare with previous tests.
		25	4			
2. AS RECEIVED (Reference Tests)	Argon	3	1, 6			- Reference tests to determine tube treatment and atmosphere effects.
		25	6, 10			
3. HYDRIDED 150 ppm UNIFORM	Argon	25	6	25	10	- Highest ppm first. Do scoping test at high strain rate to minimize time dependent effects.
				3	1, 6, 10[2]	
4. HYDRIDED 40 ppm UNIFORM	Argon	25	6	25	10	- Do low ppm only if 150 ppm tests show effect.
				3	1, 6, 10[2]	
5. AS RECEIVED	Steam+Iodine	3	6	3	1, 10[2]	- Do scoping test at low strain rate to maximize time for effects to materialize.
				25	6, 10	
6. AS RECEIVED	Argon+CO2	3	6	3	1, 10[2]	- Same reasoning as for argon + steam + iodine.
				25	6, 10	
7. AS RECEIVED	Steam	3	6	3	1, 10[2]	- Same reasoning as for argon + steam + iodine.
				25	6, 10	
8. HYDRIDED 150 ppm BLISTERED	Argon	25	6	25	10	- Late scheduling gives time to grow blisters. Scoping test same as for unblistered case.
				3	1, 6, 10[2]	
9. HYDRIDED 40 ppm BLISTERED	Argon	25	6	25	10	- Same reasoning as for 150 ppm tubes.
				3	1, 6, 10[2]	
--- IN HOT CELL ---						
10. AS RECEIVED	Argon	3	1, 6, 10[2]			- Equipment check in hot cell.
		25	6, 10			
11. IRRADIATED	Argon	3	1, 6, 10[2]			- Do these tests last as equipment will get contaminated. Do tests least likely to rupture first to simplify cleanup between tests.
		25	6, 10			

[1] - RATIONALE FOR SCOPING TESTS: If intermediate pressure test fails, do low pressure test (if part of matrix) to test ballooning and omit high pressure test.
If intermediate pressure test does not fail, do high pressure test and then low pressure test (if part of matrix) only if results are significantly different from reference.

[2] - Low priority tests - do only if time and funds permit.

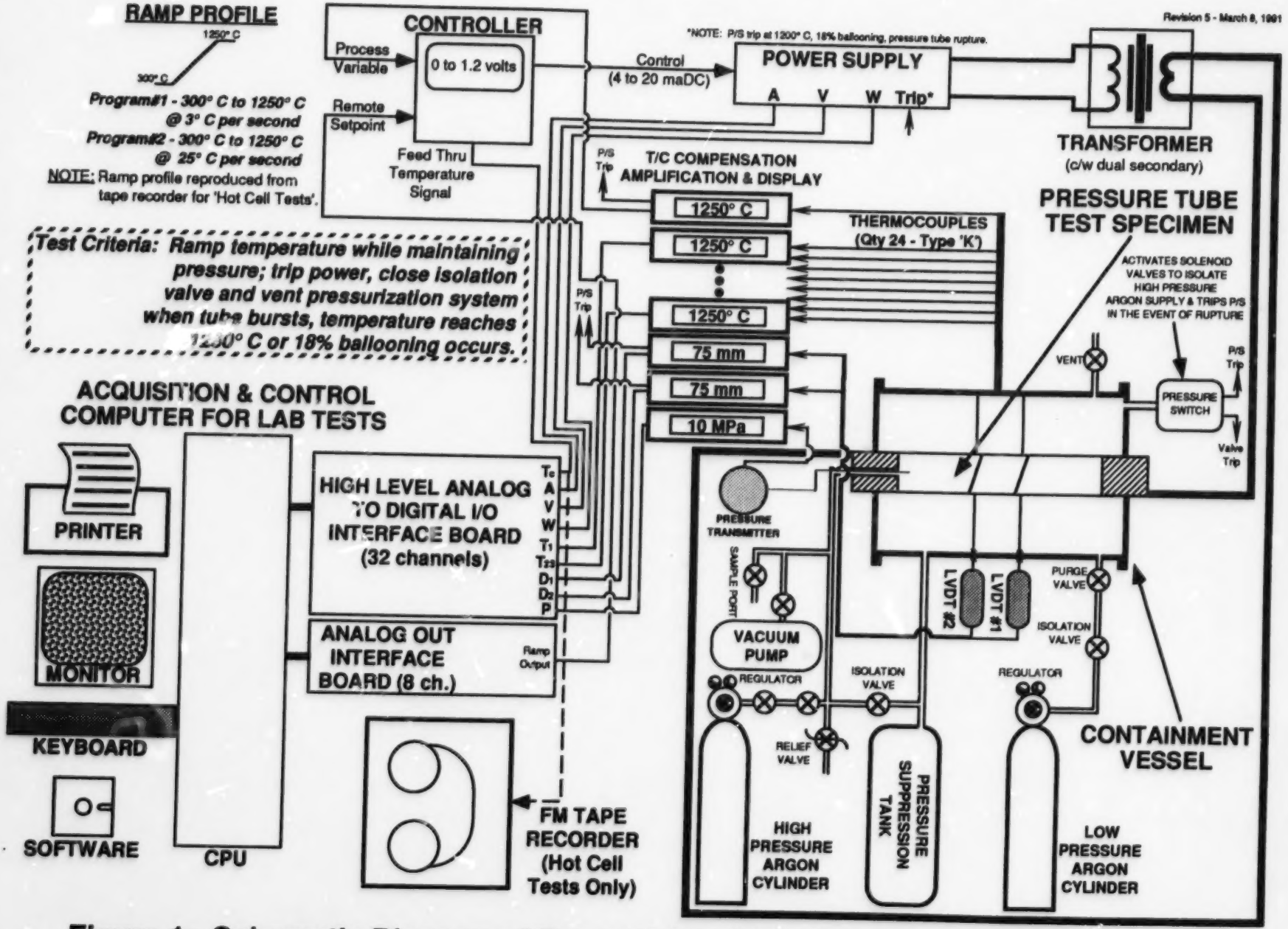

RAMP PROFILE
1250° C
300° C
Program#1 - 300° C to 1250° C @ 3° C per second
Program#2 - 300° C to 1250° C @ 25° C per second
NOTE: Ramp profile reproduced from tape recorder for 'Hot Cell Tests'.
Test Criteria: Ramp temperature while maintaining pressure; trip power, close isolation valve and vent pressurization system when tube bursts, temperature reaches 1250° C or 18% ballooning occurs.
CONTROLLER
Process Variable
Remote Setpoint
0 to 1.2 volts
Feed Thru Temperature Signal
Control (4 to 20 maDC)
*NOTE: P/S trip at 1200° C, 18% ballooning, pressure tube rupture.
POWER SUPPLY
A V W Trip*
Revision 5 - March 8, 1991
TRANSFORMER
(c/w dual secondary)
P/S Trip
T/C COMPENSATION AMPLIFICATION & DISPLAY
1250° C
1250° C
1250° C
75 mm
75 mm
10 MPa
THERMOCOUPLES (Qty 24 - Type 'K')
PRESSURE TUBE TEST SPECIMEN
ACTIVATES SOLENOID VALVES TO ISOLATE HIGH PRESSURE ARGON SUPPLY & TRIPS P/S IN THE EVENT OF RUPTURE
VENT
P/S Trip
PRESSURE SWITCH
Valve Trip
ACQUISITION & CONTROL COMPUTER FOR LAB TESTS
PRINTER
MONITOR
KEYBOARD
SOFTWARE
CPU
HIGH LEVEL ANALOG TO DIGITAL I/O INTERFACE BOARD (32 channels)
Te A V W T1 T23 D1 D2 P
ANALOG OUT INTERFACE BOARD (8 ch.)
Ramp Output
FM TAPE RECORDER (Hot Cell Tests Only)
PRESSURE TRANSMITTER
SAMPLE PORT
VACUUM PUMP
REGULATOR
RELIEF VALVE
ISOLATION VALVE
LVDT #2
LVDT #1
PURGE VALVE
ISOLATION VALVE
REGULATOR
CONTAINMENT VESSEL
HIGH PRESSURE ARGON CYLINDER
PRESSURE SUPPRESSION TANK
LOW PRESSURE ARGON CYLINDER

Figure 1: Schematic Diagram of Pressurizing & Environmental Control Circuit

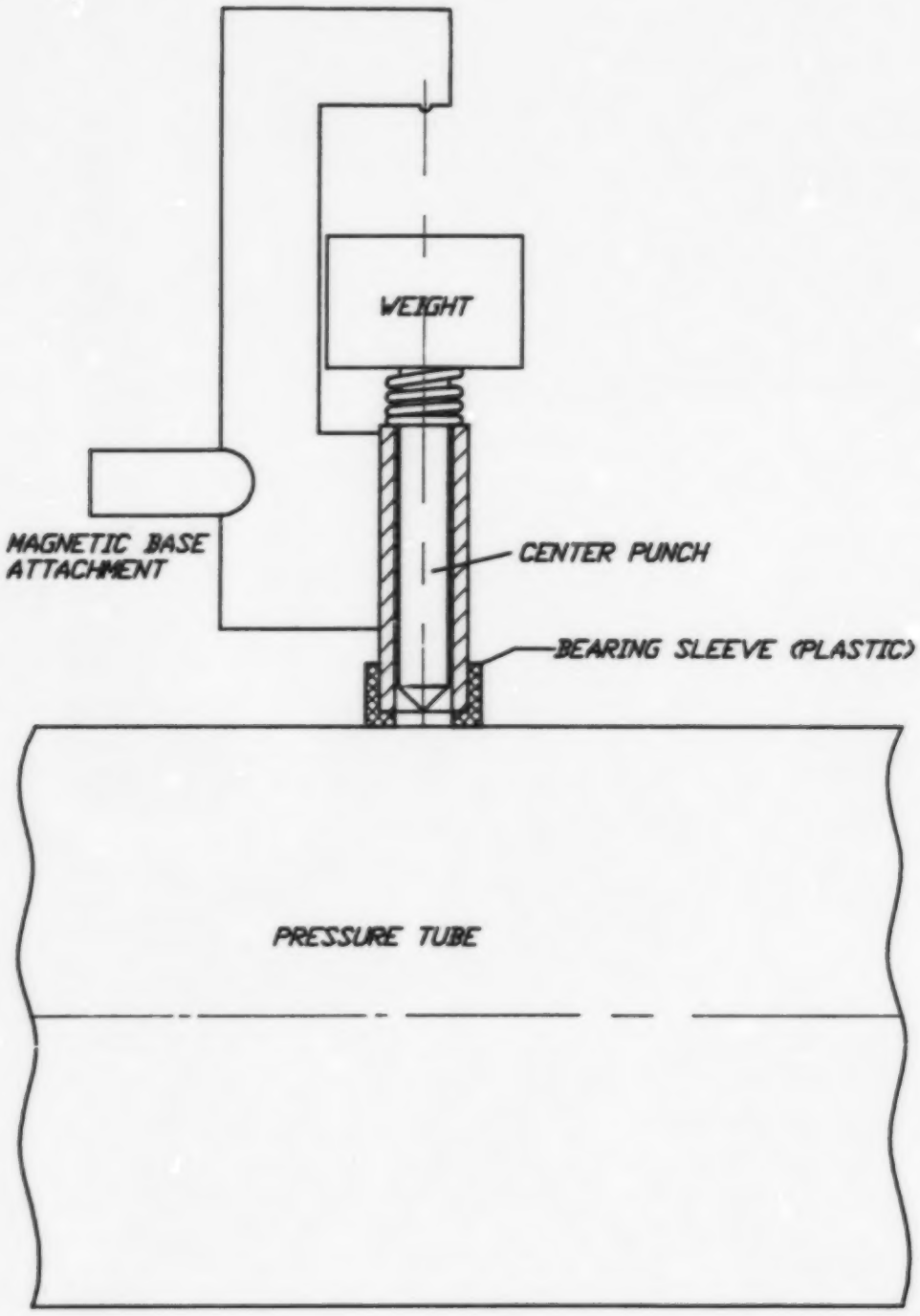
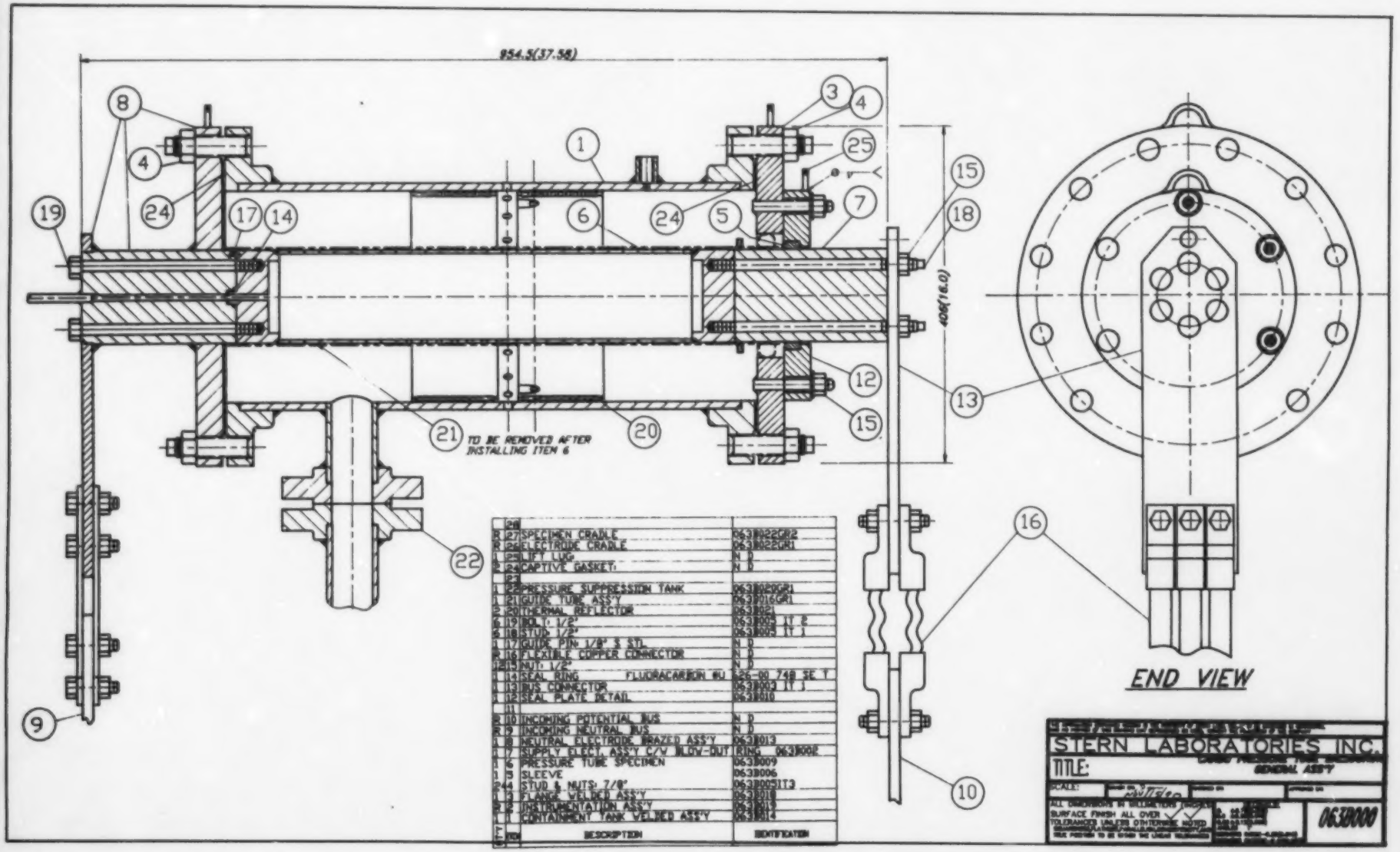


FIG. 2: CANDU PRESSURE TUBE BALLOONING PRESSURE TUBE MARKING TOOL



ITEM	QTY	DESCRIPTION	IDENTIFICATION
R	27	SPECIMEN CRADLE	0638022GR2
R	26	ELECTRODE CRADLE	0638022GR1
R	25	LIFT LUG	N.D
R	24	CAPTIVE GASKET	N.D
1	23	PRESSURE SUPPRESSION TANK	0638020GR1
1	21	GUIDE TUBE ASS'Y	0638016GR1
2	20	THERMAL REFLECTOR	0638021
6	19	BOLT 1/2"	0638005 LT 2
6	18	STUD 1/2"	0638005 LT 1
1	17	GUIDE PIN 1/8" Ø STD.	N.D
2	16	FLEXIBLE COPPER CONNECTOR	N.D
12	15	NUT 1/2"	N.D
1	14	SEAL RING FLUOROCARBON #U	226-00 748 SE Y
1	13	BUS CONNECTOR	0638003 LT 1
1	12	SEAL PLATE DETAIL	0638010
	11		
2	10	INCOMING POTENTIAL BUS	N.D
R	9	INCOMING NEUTRAL BUS	N.D
1	8	NEUTRAL ELECTRODE BRAZED ASS'Y	0638013
1	7	SUPPLY ELECT. ASS'Y C/W BLOW-OUT	RING 0638008
1	6	PRESSURE TUBE SPECIMEN	0638009
1	5	SLEEVE	0638006
24	4	STUD & NUTS: 7/8"	0638005LT3
1	3	FLANGE WELDED ASS'Y	0638011
2	2	INSTRUMENTATION ASS'Y	0638012
1	1	CONTAINMENT TANK WELDED ASS'Y	0638014

STERN LABORATORIES INC.

TITLE: GENERAL ASS'Y

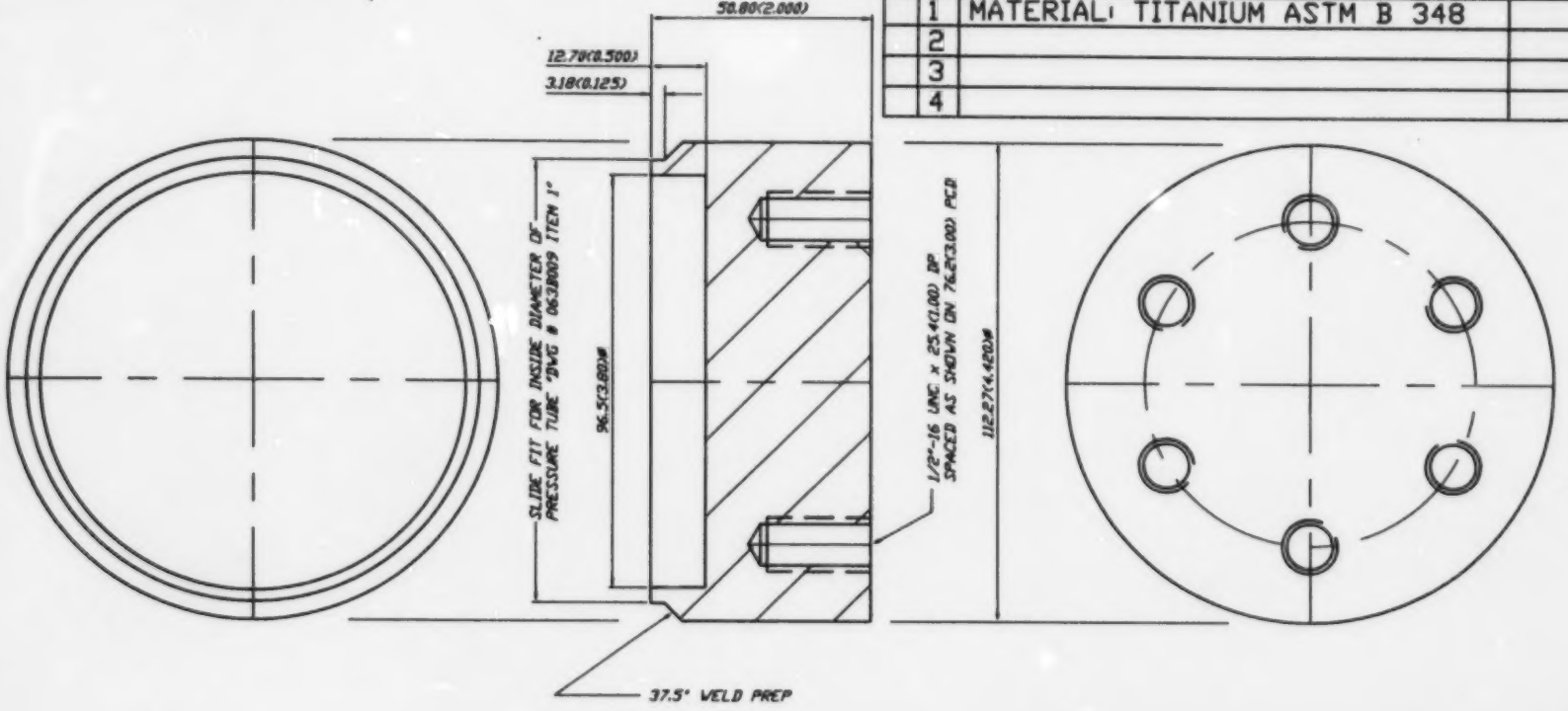
SCALE:

SURFACE FINISH ALL OVER

TOLERANCES UNLESS OTHERWISE NOTED

0638000

QTY	ITEM	DESCRIPTION	IDENTIFICATION
	1	MATERIAL: TITANIUM ASTM B 348	
	2		
	3		
	4		


50.80(2.000)
12.70(0.500)
3.18(0.125)
SLIDE FIT FOR INSIDE DIAMETER OF PRESSURE TUBE "DWG # 063B009 ITEM 1"
96.52(3.80)
1/2"-16 UNC x 25.40(1.00) DP SPACED AS SHOWN ON 76.2(3.00) PCD
112.27(4.420)
37.5° WELD PREP

REVISION	SHOP ORDER NO.
1	
2	

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STERN LABORATORIES INC.

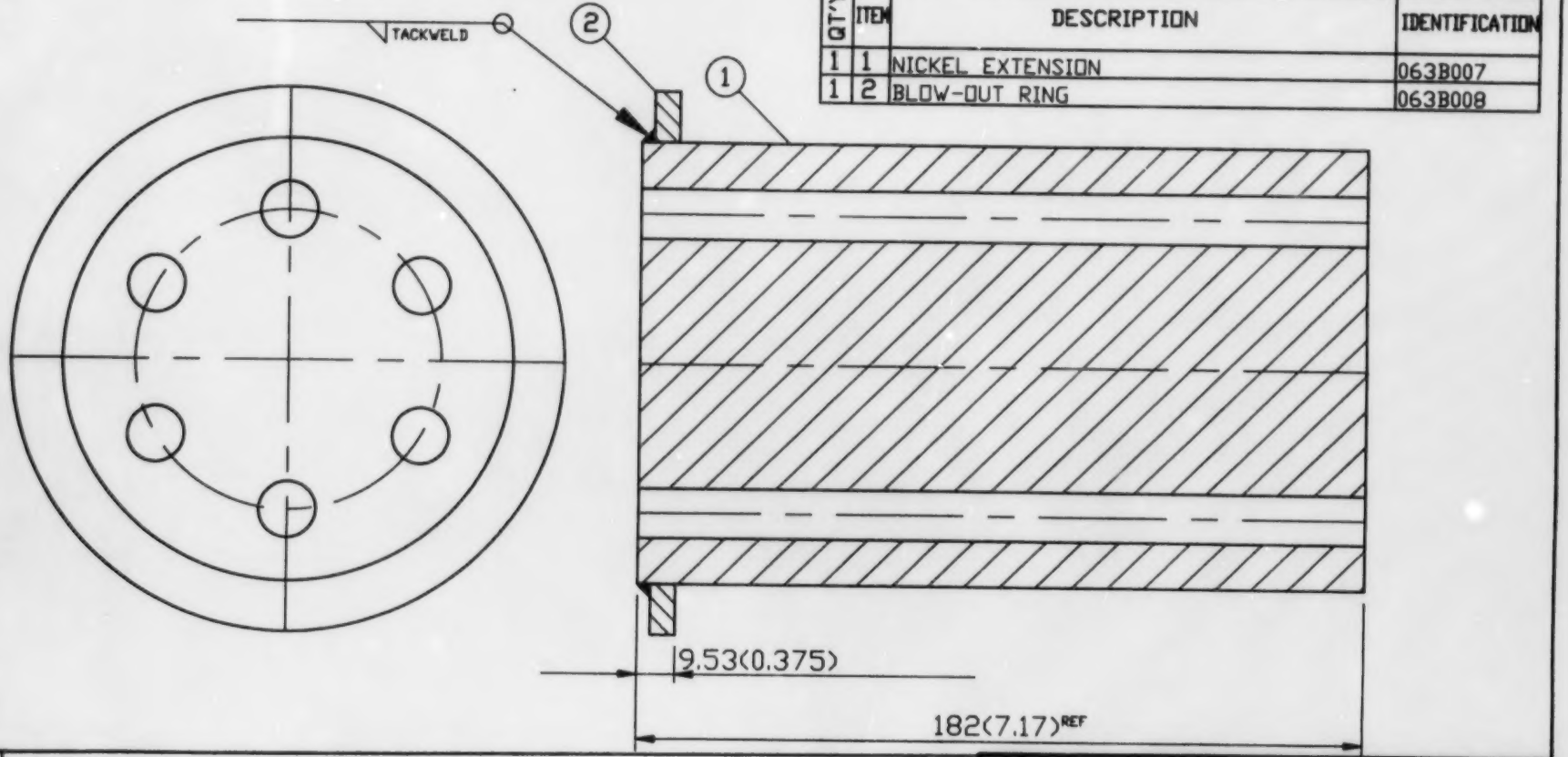
TITLE: CANDU PRESSURE TUBE BALLOONING
END CAP DETAIL - SUPPLY END

SCALE: FULL | DRAWN BY: [illegible] /FEB/11/99 | CHECKED BY: | APPROVED BY:

ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

DECIMALS
0. ±0.7(0.030)
0.0 ±0.38(0.015)
0.00 ±0.13(0.005)
ANGLES
CORNERS RADII: -0.38(0.015)
CORNERS BUTTED: -0.127(0.005)

063B001



QT'Y	ITEM	DESCRIPTION	IDENTIFICATION
1	1	NICKEL EXTENSION	063B007
1	2	BLOW-OUT RING	063B008

STOP ORDER NO.	REVISION
1	2

STERN LABORATORIES INC.

TITLE CANDU PRESSURE TUBE BALLOONING
NICKEL EXTENSION WELDED ASS'Y- SUPPLY END

SCALE: | DRAWN BY: | DESIGNED BY: | APPROVED BY:

ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

ANGLES
CORNERS INSIDE

063B002

QTY	ITEM	DESCRIPTION	IDENTIFICATION
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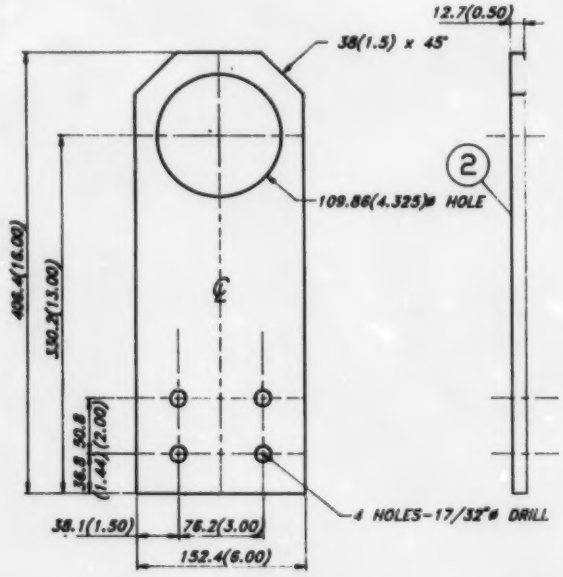
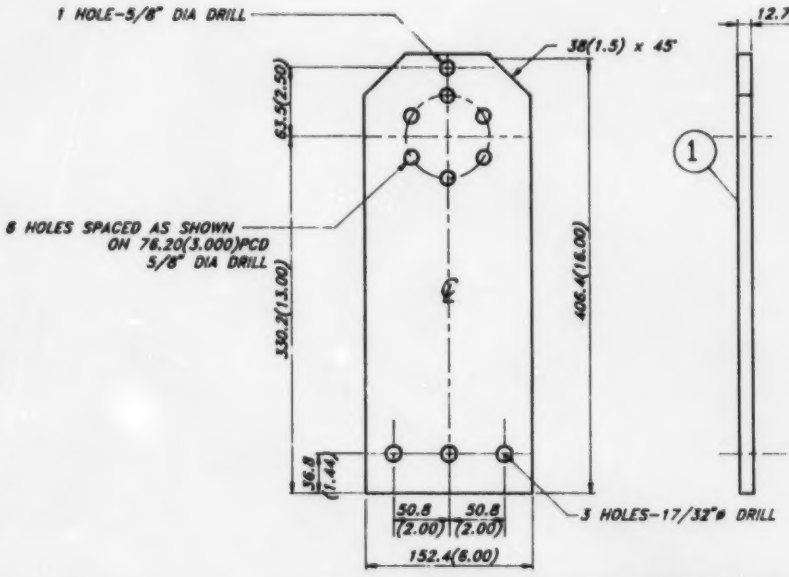
	2	MAT: 1/2" THK COPPER	





SHOP ORDER NO.	REVISION
1	2

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STERN LABORATORIES INC.

TITLE: CANDU PRESSURE TUBE BALLOONING
COPPER BUS CONNECTION DETAILS

SCALE: | DRAWN BY: DA/NBJ/16/91 | CHECKED BY: | APPROVED BY:

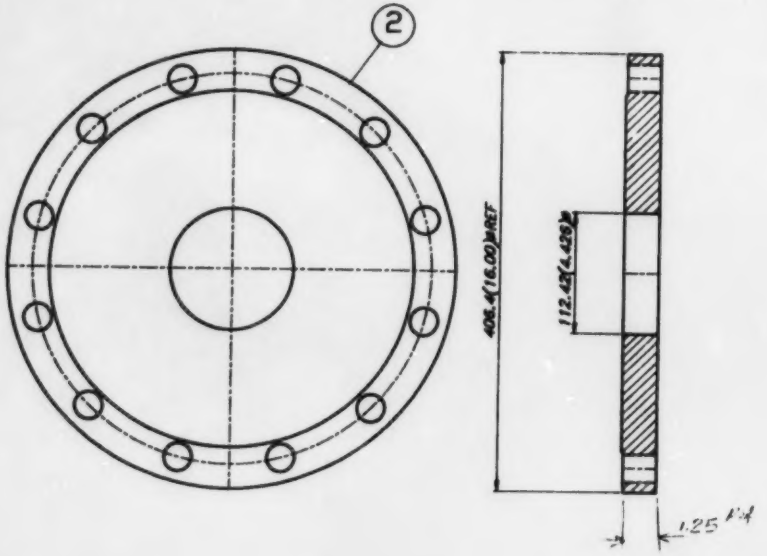
ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

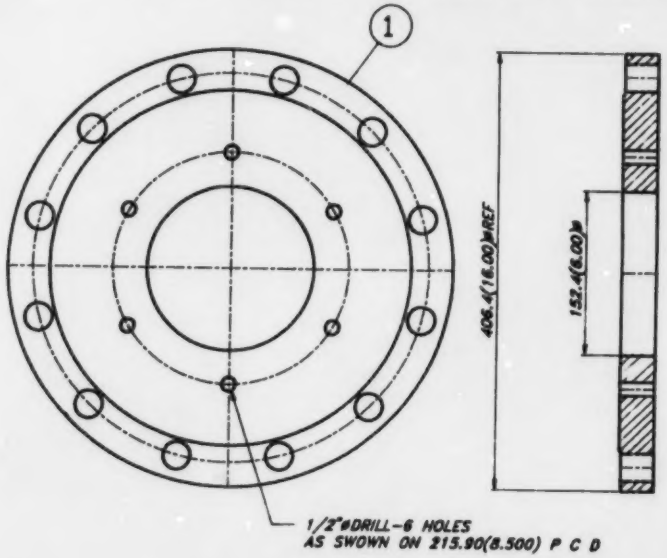
TOLERANCES
0. ±0.75(0.030)
0.0 ±0.25(0.010)
0.00 ±0.13(0.005)
ANGLES 1°
CORNERS INSIDE-0.25(0.010)
CORNERS OUTSIDE-0.50(0.020)

0638003

QTY	ITEM	DESCRIPTION	IDENTIFICATION
	1	MAT: 10" BLIND FLANGE - 150# S STL	
	2	MAT: 10" BLIND FLANGE - 150# S STL	

NOTE: REMOVE ALL BURRS & SHARP EDGES





NO.	REVISION	SHOP ORDER NO.
1		
2		

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STERN LABORATORIES INC.

TITLE: CANDU PRESSURE TUBE BALLOONING
BLIND FLANGE MACHINING DETAIL

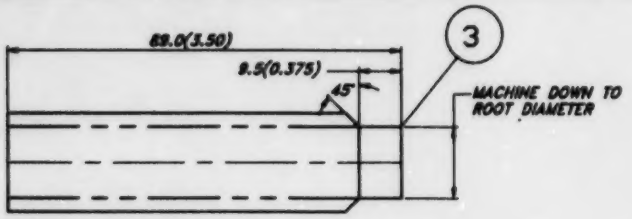
SCALE: 1/4 | DRAWN BY: [illegible] | CHECKED BY: | APPROVED BY:

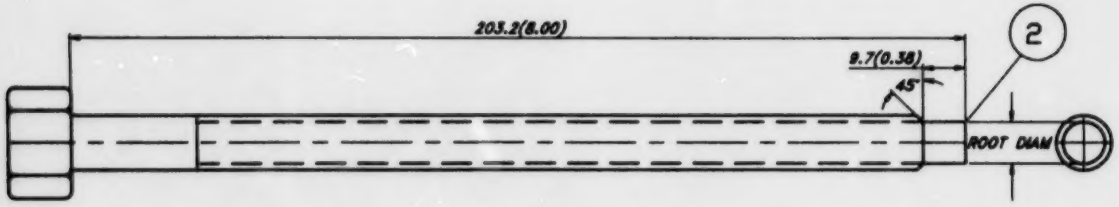
ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

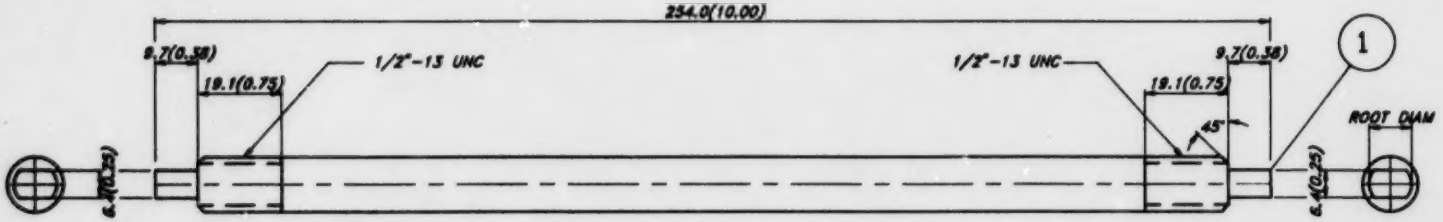
UNLESS NOTED
0 ±0.77(0.030)
1.0 ±0.25(0.010)
0.02 ±0.13(0.005)
ANGLES
CORNERS INSIDE-0.25(0.010)
CORNERS OUTSIDE-0.40(0.016)

063B004

QTY	ITEM	DESCRIPTION	IDENTIFICATION
	1	MAT: 1/2" DIA S STL ROD	
	2	MAKE FROM 1/2"-13 UNC x 8"LG BOLT	
	3	MAKE FROM 7/8" FLANGE BOLT	







SHOP ORDER NO.	REVISION
1	
2	

STERN LABORATORIES INC.

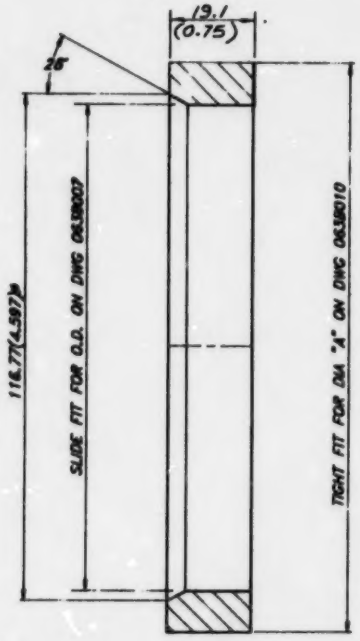
TITLE: CANDU PRESSURE TUBE BALLOONING
BOLT DETAILS

SCALE:

ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED

063B005

QT'Y	ITEM	DESCRIPTION	IDENTIFICATION
	1	MAT: MACHINABLE CERAMIC	
	2		



SHOP ORDER NO.

REVISION	
1	
2	

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STERN LABORATORIES INC.

TITLE: • CANDU PRESSURE TUBE BALLOONING
• CERAMIC SLEEVE DETAIL

SCALE: FULL | DRAWN BY: MAY/15/90 | DESIGNED BY: | APPROVED BY:

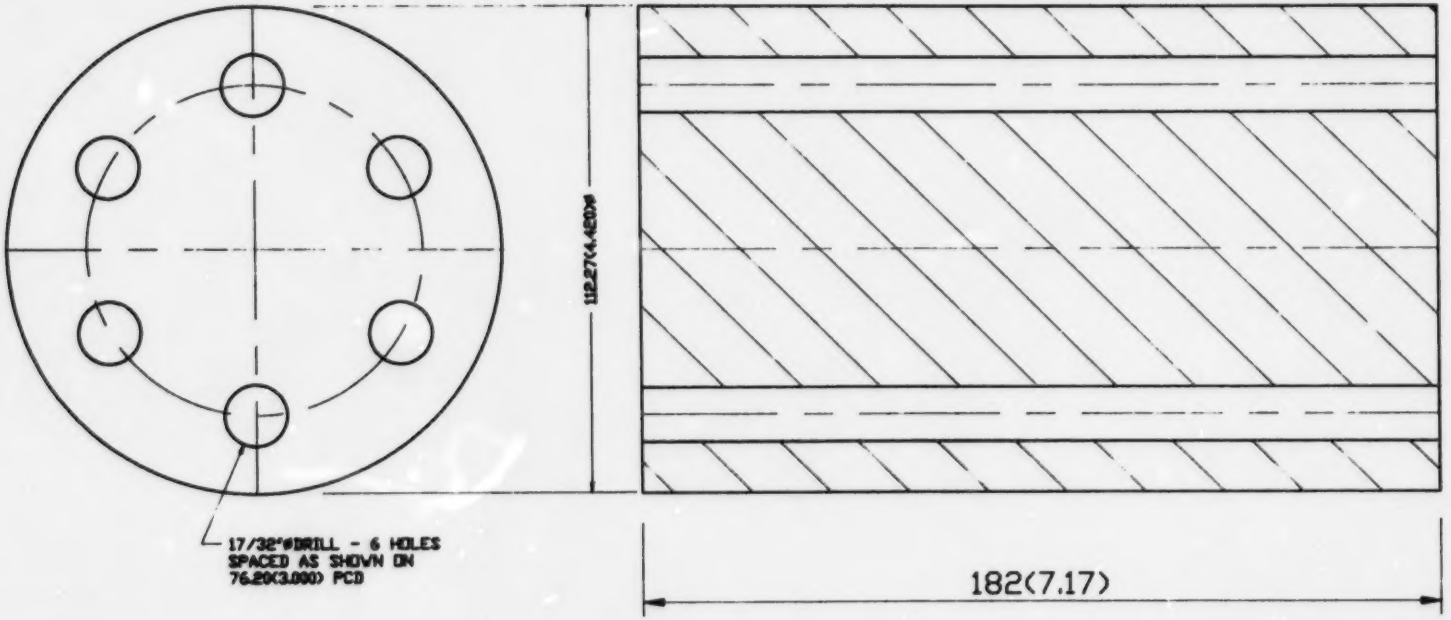
ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER ✓
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

DECIMALS
0. ±0.7(0.030)
0.0 ±0.25(0.010)
0.00 ±0.12(0.005)
ANGLES ±1°
CORNERS INSIDE-0.25(0.010)
CORNERS OUTSIDE-0.40(0.015)

063B006

QT'Y	ITEM	DESCRIPTION	IDENTIFICATION
	1	MATERIAL: NICKEL 200	
	2		

NOTE: REMOVE ALL BURRS & SHARP EDGES



SHOP ORDER NO.

REVISION	
1	
2	

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STERN LABORATORIES INC.

TITLE: • CANDU PRESSURE TUBE BALLOONING
• NICKEL EXTENSION DETAIL – SUPPLY END

SCALE: FULL | DRAWN BY: Apr. /NBJ/ 15/70 | CHECKED BY: | APPROVED BY:

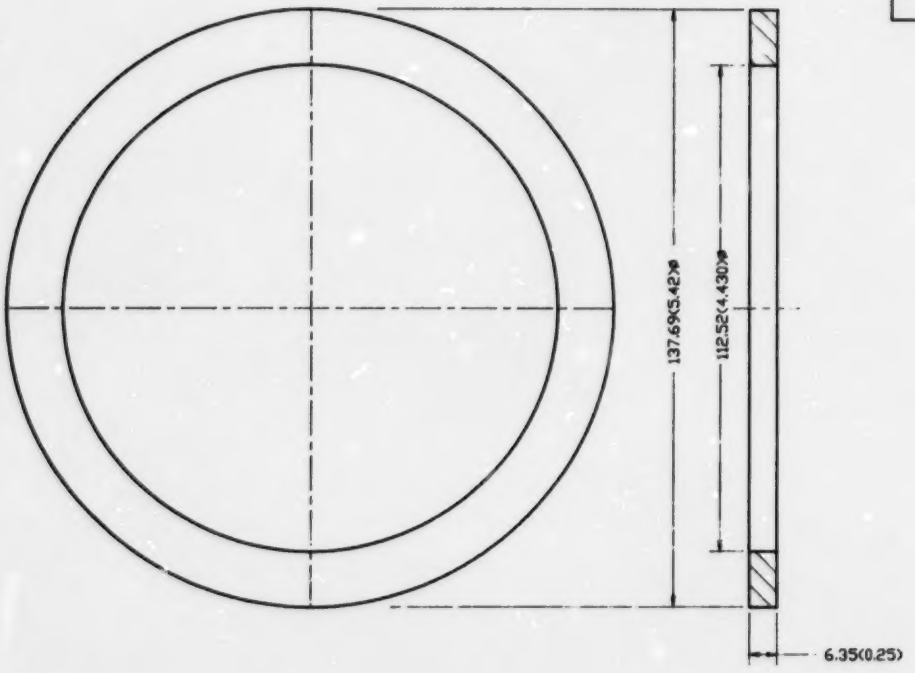
ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

DECIMALS
0. ±0.75(0.030)
0.0 ±0.25(0.010)
0.00 ± 0.13 (0.005)
ANGLES 1°
CORNERS INSIDE – 0.25(0.010)
CORNERS OUTSIDE – 0.50(0.020)

063B007

QT'Y	ITEM	DESCRIPTION	IDENTIFICATION
	1	MATERIAL: 304 S STL	
	2		

NOTE: REMOVE ALL BURRS & SHARP EDGES



SHOP ORDER NO.

REVISION	
1	
2	

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STERN LABORATORIES INC.

TITLE: CANDU PRESSURE TUBE BALLOONING
BLOWOUT RING DETAIL

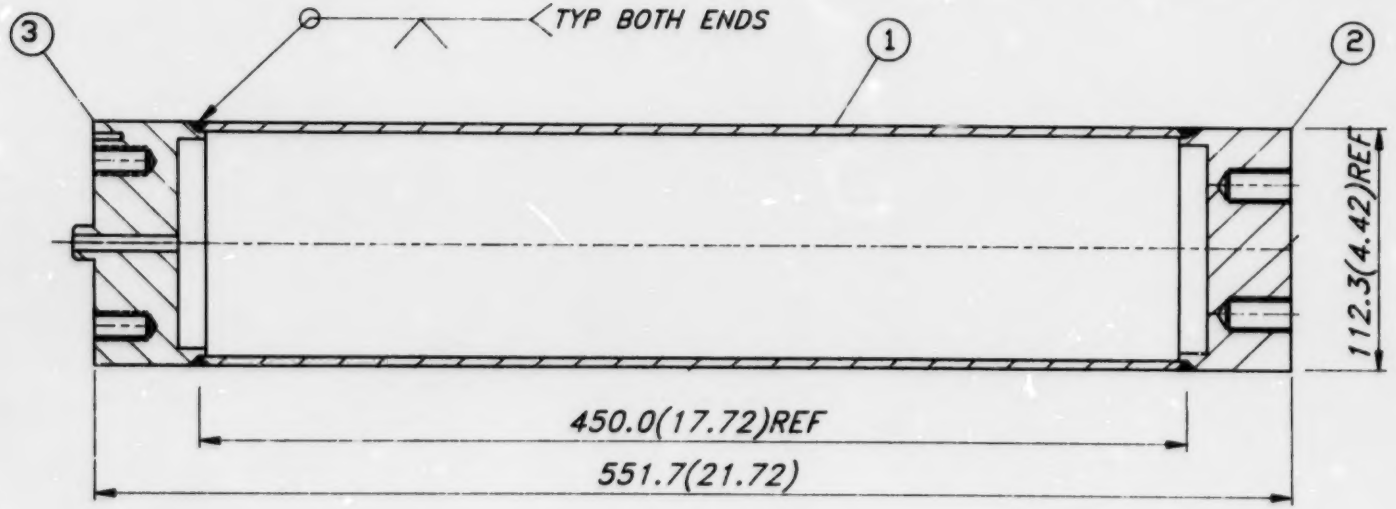
SCALE: FULL | DRAWN BY: [illegible] | CHECKED BY: | APPROVED BY:

ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

DECIMALS
0.0 ±0.75(0.030)
0.00 ±0.25(0.010)
0.000 ±0.13(0.005)
ANGLES ±1°
CORNERS INSIDE-0.25(0.010)
CORNERS OUTSIDE-2.50(0.015)

063B008

QT'Y	ITEM	DESCRIPTION	IDENTIFICATION
1	1	Zr-2.5 wt% Nb PRESSURE TUBE	
1	2	END CAP - SUPPLY END	063B001
1	3	END CAP - NEUTRAL END	063B012
	4		



NO.	REVISION	S.O.P. ORDER NO.
1		
2		

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STERN LABORATORIES INC.

TITLE: CANDU PRESSURE TUBE BALLOONING PRESSURE TUBE SPECIMEN

SCALE: 1/2 | DRAWN BY: JWD/JRT | CHECKED BY: | APPROVED BY:

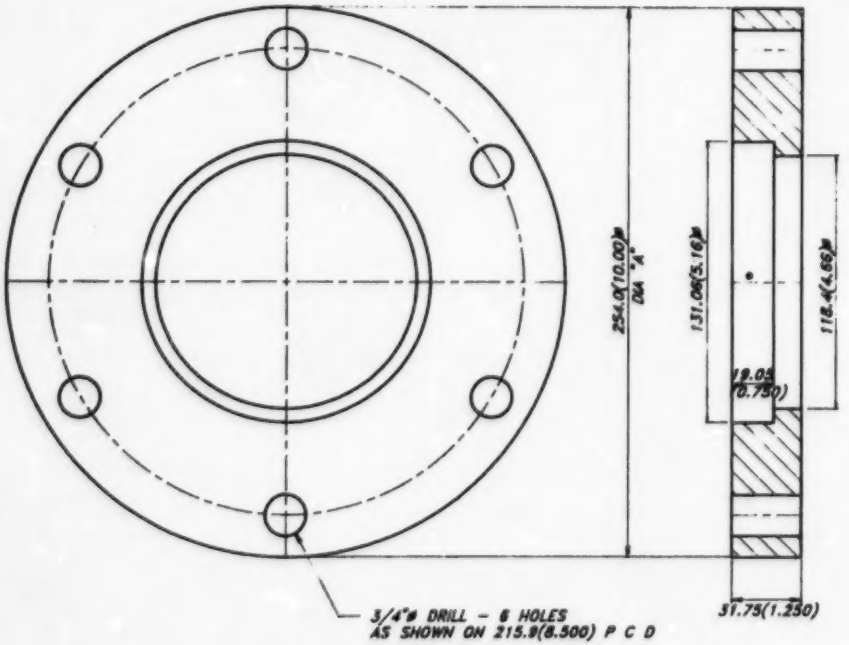
ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHTERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

DECIMALS	
0.	±0.75(0.030)
0.0	±0.25(0.010)
0.00	±0.12(0.005)
ANGLES	1°
CORNERS INSIDE	-0.25(0.010)
CORNERS OUTSIDE	-0.65(0.015)

063B009

QTY	ITEM	DESCRIPTION	IDENTIFICATION
	1	MATERIAL: 1.25" THK 304 S STL	
	2		

NOTE: REMOVE ALL BURRS & SHARP EDGES



NO.	REVISION	SHOP ORDER NO.
1		
2		

THE INFORMATION CONTAINED HEREIN IS THE PROPERTY OF STERN LABS, INC. MUST BE MAINTAINED IN CONFIDENCE, AND NO PORTION OF THIS DRAWING MAY REPRODUCED OR USED, WITHOUT THE PERMISSION OF THE COMPANY

STERN LABORATORIES INC.

TITLE: CANDU PRESSURE TUBE BALLOONING
SEAL PLATE DETAIL

SCALE: 1/2 | DRAWN BY: [illegible] | CHECKED BY: | APPROVED BY:

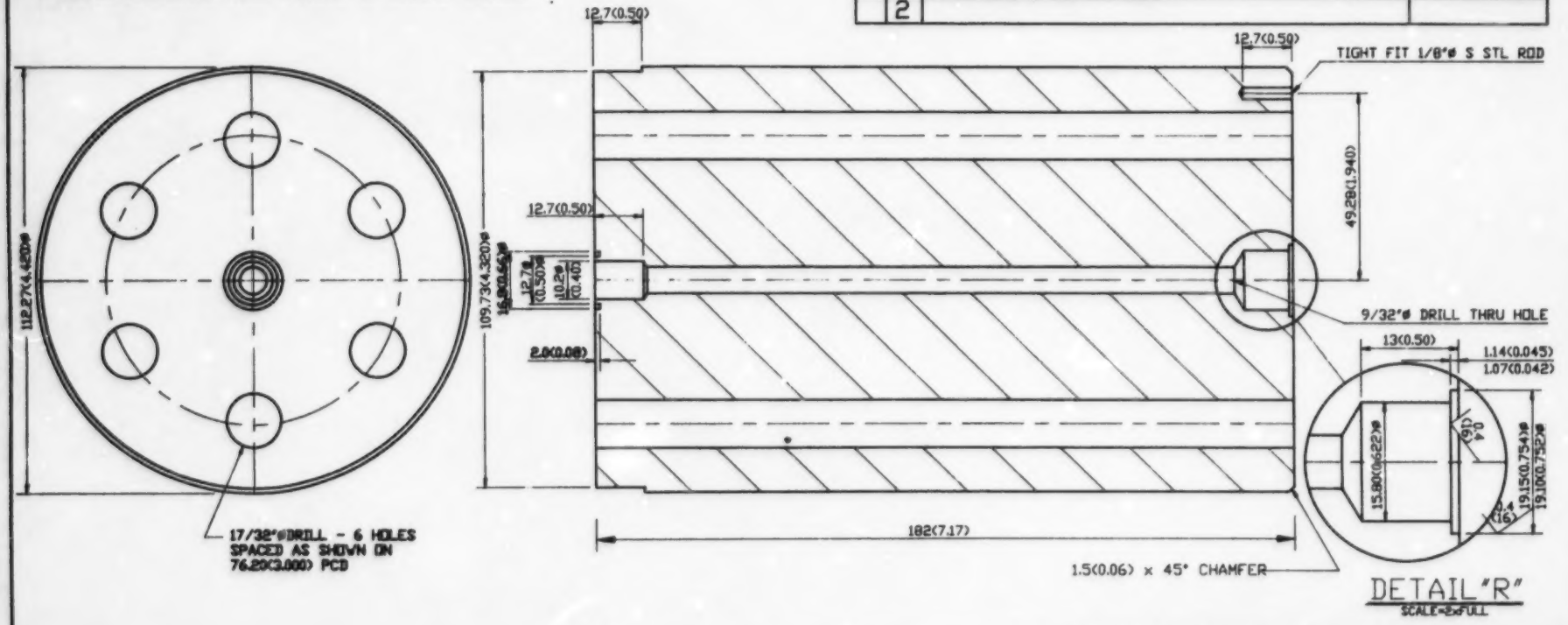
ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

0.	±0.75(0.030)
0.0	±0.25(0.010)
0.00	±0.12(0.005)
ANGLES	1°
CORNERS INSIDE	-0.25(0.010)
CORNERS OUTSIDE	-0.40(0.015)

063B010

NOTE: REMOVE ALL BURRS & SHARP EDGES

QT'Y	ITEM	DESCRIPTION	IDENTIFICATION
	1	MATERIAL: NICKEL 200	
	2		



NO.	REVISION	SHOP ORDER NO.
1		
2		

THE INFORMATION CONTAINED HEREIN IS THE PROPERTY OF STERN LABS, INC. MUST BE MAINTAINED IN CONFIDENCE, AND NO PORTION OF THIS DRAWING MAY REPRODUCED OR USED, WITHOUT THE PERMISSION OF THE COMPANY

STERN LABORATORIES INC.

TITLE: CANDU PRESSURE TUBE BALLOONING
NICKEL EXTENSION DETAIL – NEUTRAL END

SCALE: FULL | DRAWN BY: MCH/15/Feb | CHECKED BY: | APPROVED BY:

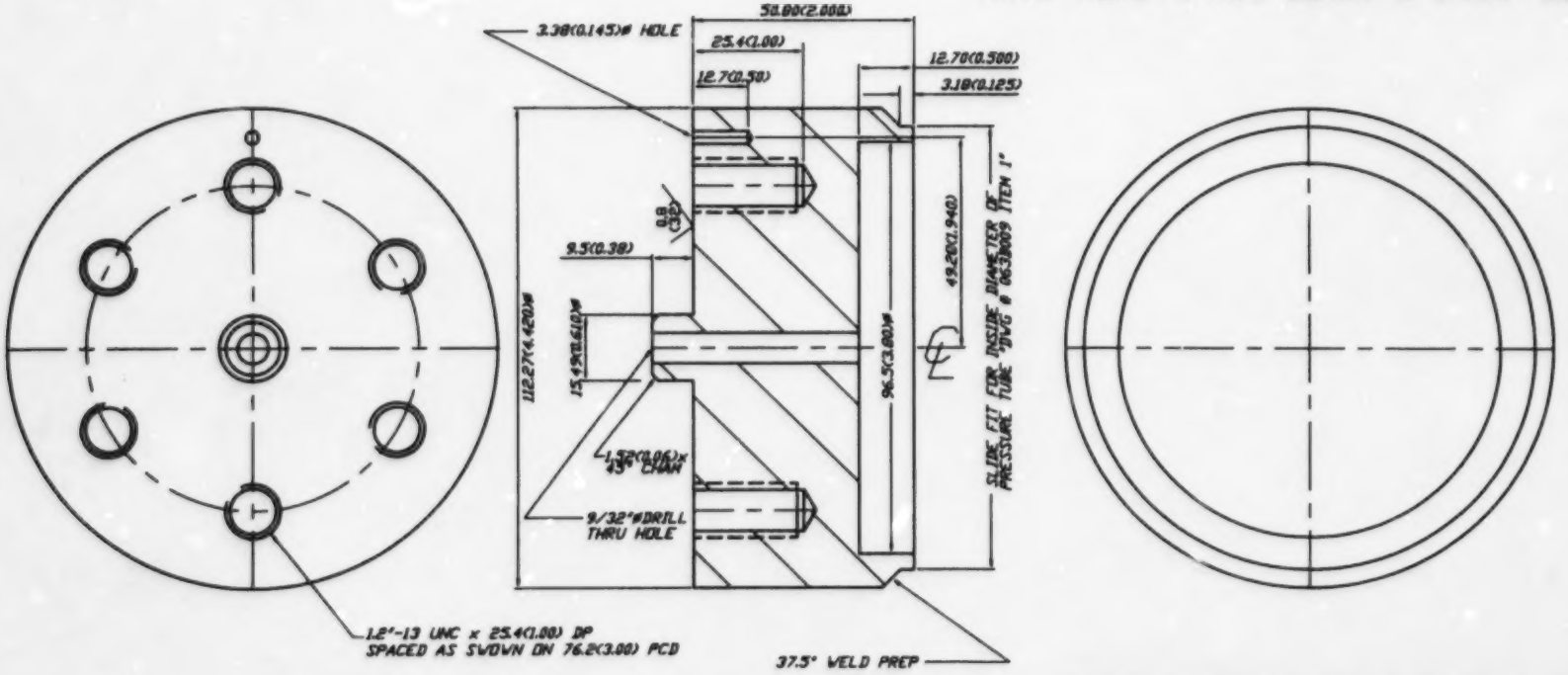
ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

DECIMALS
n ±0.75(0.030)
0.0 ±0.25(0.010)
0.00 ±0.13(0.005)
ANGLES 1°
CORNERS INSIDE -0.25(0.010)
CORNERS OUTSIDE -0.40(0.015)

063B011

QT'Y	ITEM	DESCRIPTION	IDENTIFICATION
	1	MATERIAL: TITANIUM ASTM B 348	

NOTE: REMOVE ALL BURRS & SHARP EDGES



NO.	REVISION	SHOP ORDER NO.
1		
2		

THE INFORMATION CONTAINED HEREIN IS THE PROPERTY OF STERN LABS, INC. MUST BE MAINTAINED IN CONFIDENCE, AND NO PORTION OF THIS DRAWING MAY REPRODUCED OR USED, WITHOUT THE PERMISSION OF THE COMPANY

STERN LABORATORIES INC.

TITLE: CANDU PRESSURE TUBE BALLOONING
END CAP DETAIL - NEUTRAL END

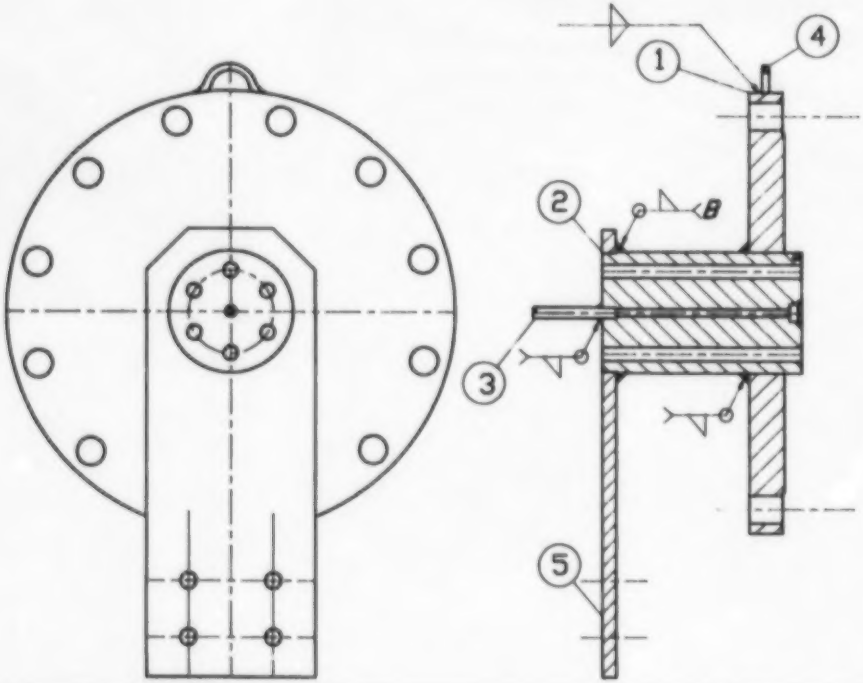
SCALE: FULL | DRAWN BY: [illegible] | CHECKED BY: | APPROVED BY:

ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

DECIMALS
.X ±0.75(0.030)
.XX ±0.25(0.010)
.XXX ±0.13(0.005)
ANGLES ±1°
CORNERS RADII -0.25(0.01")
CORNERS (3.175)R -0.40(0.01")

063B012

ITEM	QTY	DESCRIPTION	IDENTIFICATION
1	1	BLIND FLANGE	063B014
2	1	NICKEL EXTENSION	063B011
3	1	1/8" S.S.TL. TUBING	
4	1	LIFTING LUG	
5	1	COPPER BUS DETAIL	063B003



NO.	REVISION	SHOP ORDER NO.
1		
2		

THE INFORMATION CONTAINED HEREIN IS THE PROPERTY OF STERN LABS, INC. AND IS LOANED IN CONFIDENCE. NO PORTION OF THIS DRAWING MAY BE REPRODUCED OR USED, WITHOUT THE PERMISSION OF THE CORP. HEAD

STERN LABORATORIES INC.

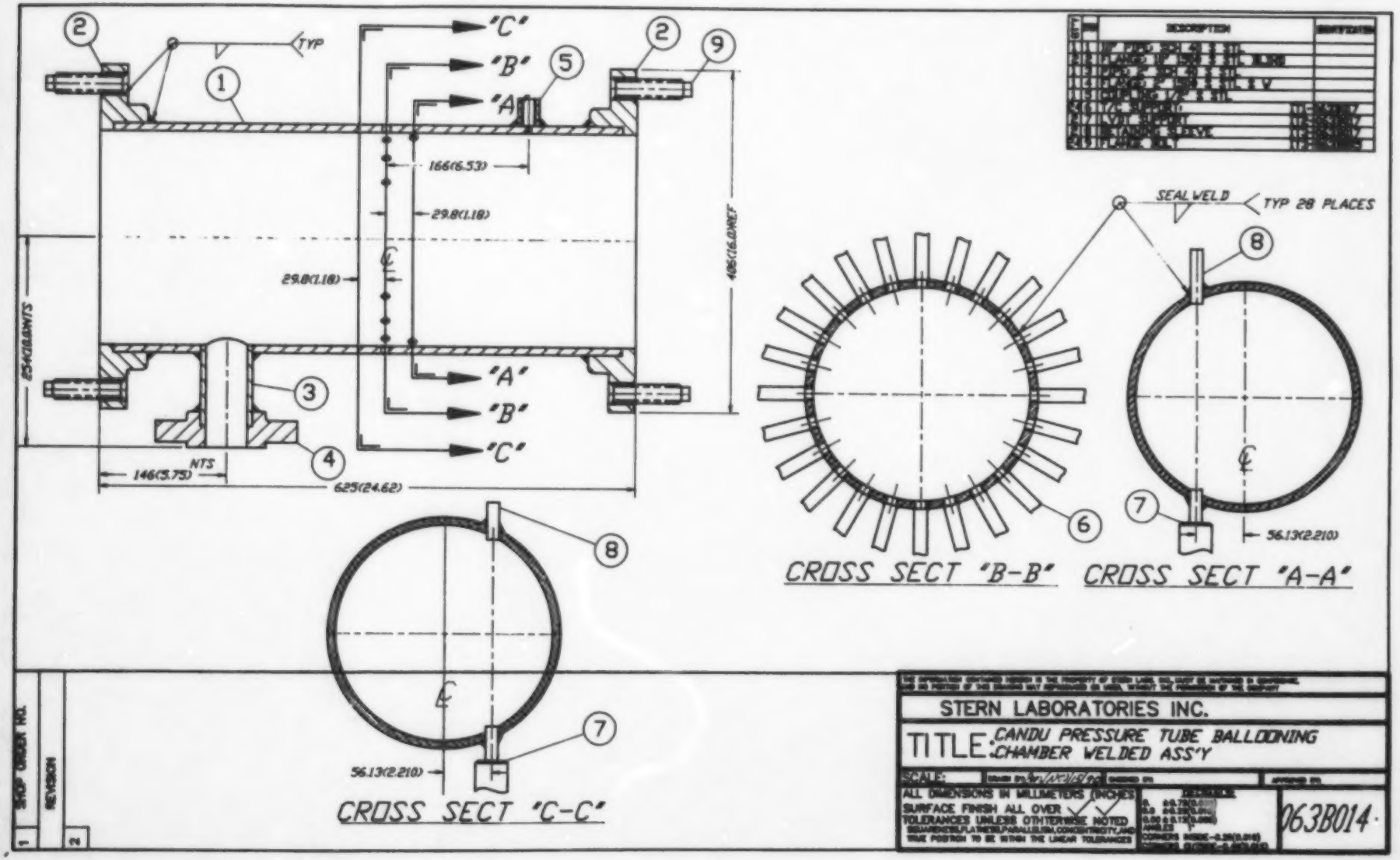
TITLE: • CANDU PRESSURE TUBE BALLOONING
• NEUTRAL ELECTRODE ASS'Y

SCALE: full | DRAWN BY: Jim MOWLES | CHECKED BY: | APPROVED BY:

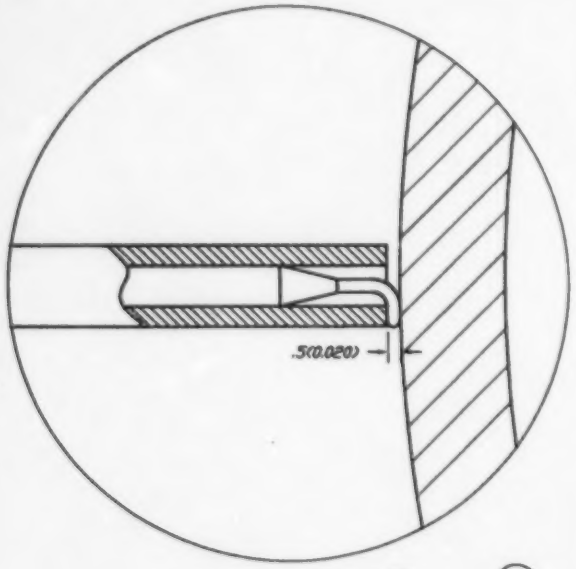
ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

DECIMALS
0. ±0.13 (0.030)
0.0 ±0.38 (0.015)
0.00 ±0.127 (0.005)
ANGLES ±°
CORNERS INSIDE -0.38 (0.015)
CORNERS OUTSIDE -0.127 (0.005)

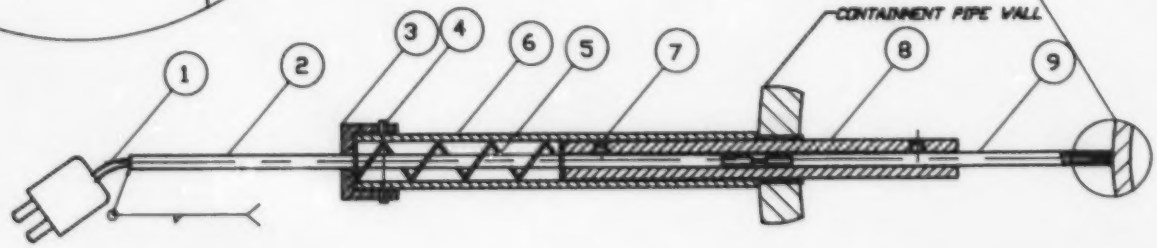
063B013


"C"
"B"
"A"
TYP
166(6.53)
29.8(1.18)
406(16.0)REF
254(10.0)NTS
146(5.75) NTS
625(24.62)
SEAL WELD
TYP 28 PLACES
56.13(2.210)
CROSS SECT "B-B"
CROSS SECT "A-A"
CROSS SECT "C-C"
STERN LABORATORIES INC.
TITLE: CANDU PRESSURE TUBE BALLOONING CHAMBER WELDED ASS'Y
ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
063B014

QTY	ITEM	DESCRIPTION	IDENTIFICATION
	1	1/16" TYPE "K" INCONEL SHEATHED THERMOCOUPLE	
	2	1/8" OD x 1/16" ID S STL TUBE	
	3	CAP	
	4	PINS: 1/8" DIA S STL	
	5	INCONEL SPRING VIL-0.8mm PITCH-5mm FL-50mm	
	6	TUBE	
	7	SET SCREWS 84-48 UNF	
	8	GUIDE TUBE: MAKE FROM 1/2" DIA S STL ROD	
	9	ALUMINA TUBE -1/8" OD x 1/16" ID	
	10		
	11		
	12		



DETAIL "T/C"



SHOP ORDER NO.

REVISION	
1	
2	

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STERN LABORATORIES INC.

TITLE: CANDU PRESSURE TUBE BALLOONING T/C ASS'Y

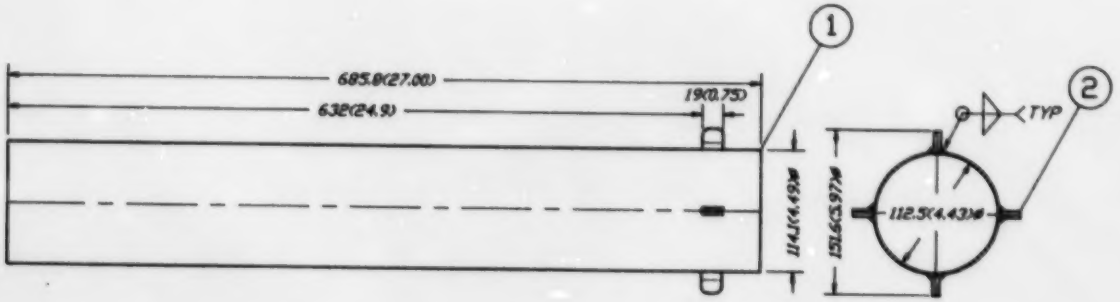
SCALE: 1/4 | DRAWN BY: B. MOY 15/90 | CHECKED BY: | APPROVED BY:

ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

DECIMALS	
0.	±0.75(0.030)
0.0	±0.25(0.010)
0.00	±0.13(0.005)
ANGLES	°
CORNERS INSIDE	-0.25(0.010)
CORNERS OUTSIDE	-0.50(0.020)

063B015

QTY	ITEM	DESCRIPTION	IDENTIFICATION
1	1	TUBE, S STL	
4	2	PADS, S STL	



SHOP ORDER NO.

REVISION	
1	
2	

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STERN LABORATORIES INC.

TITLE CANDU PRESSURE TUBE BALLOONING GUIDE TUBE

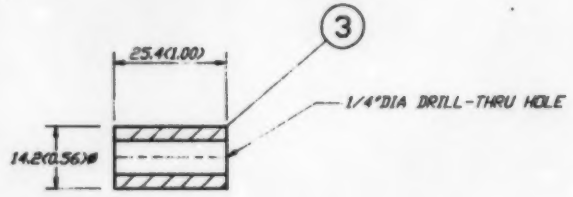
SCALE: 1/2" | DRAWN BY: [illegible] 21/2/13 | CHECKED BY: | APPROVED BY:

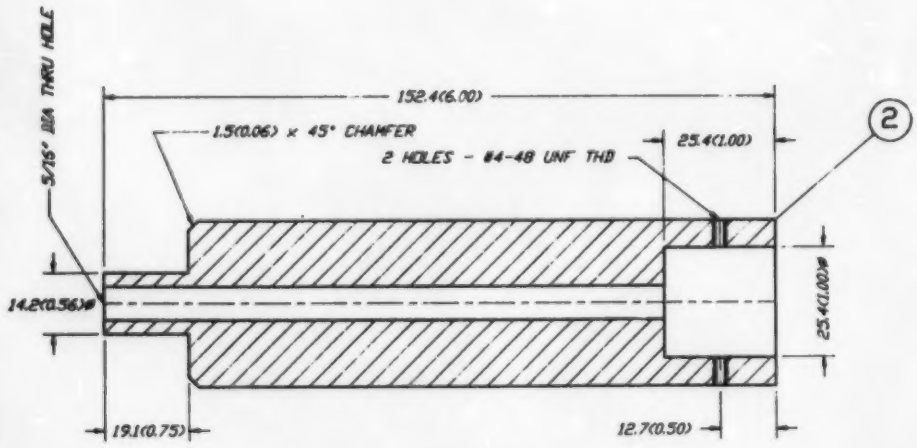
ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, PLATENESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

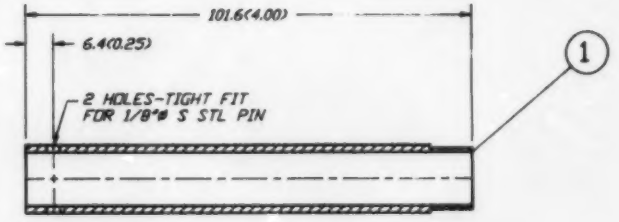
DECIMALS
0. ±0.7(0.030)
0.0 ±0.25(0.010)
0.00 ±0.12(0.005)
ANGLES 1°
CORNERS INSIDE-0.25(0.010)
[illegible]

063B016

QTY	ITEM	DESCRIPTION	IDENTIFICATION
	1	MAT: 5/8" DIA x(0.065) THK WALL S STL TUBE	
	2	MAT: 1.5" DIA S STL ROD	
	3	MAT: 9/16" DIA S STL ROD	
	4		







SHOP ORDER NO.

REVISION	
1	
2	

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STERN LABORATORIES INC.

TITLE: CANDU PRESSURE TUBE BALLOONING
T/C & LVDT S STL DETAILS

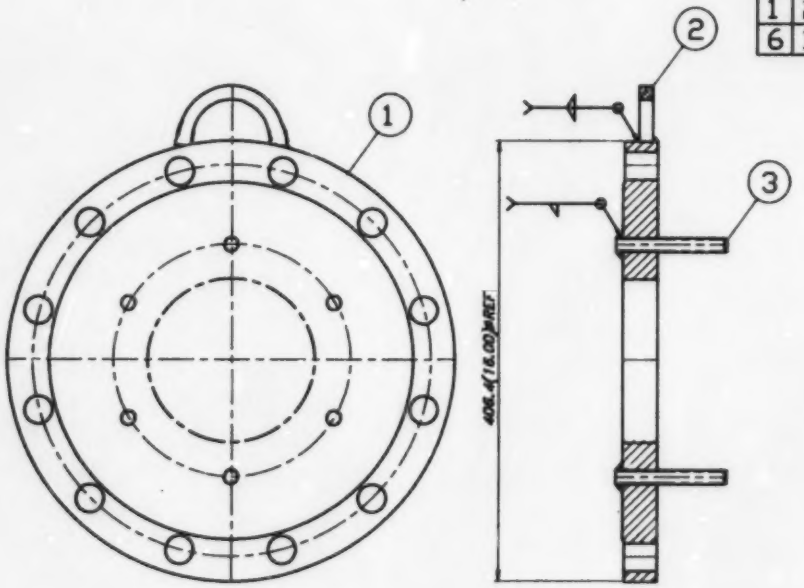
SCALE: NTS | DRAWN BY: JN/NOV/15/Pd | CHECKED BY: | APPROVED BY:

ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

.X	±0.2(0.020)
.0.0	±0.25(0.010)
0.00	±0.13(0.005)
ANGLES	°
CORNERS	RADIUS -0.25(0.010)
CHAMFER	(0.12)X45°-0.40(0.015)

063B017

QT'Y	ITEM	DESCRIPTION	IDENTIFICATION
1	1	FLANGE:	IT1-063B004
1	2	LIFTING LUG:	ND
6	1	STUDS: 1/2"-13 UNC x 2.5" LG S STL	ND



NOTE: REMOVE ALL BURRS & SHARP EDGES

SHOP ORDER NO.	REVISION
1	2

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STERN LABORATORIES INC.

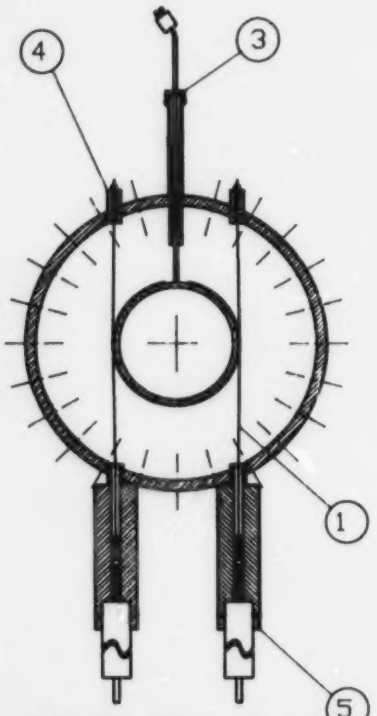
TITLE: *CANDU PRESSURE TUBE BALLOONING*
FLANGE WELDED ASS'Y

SCALE: 1/4 | DRAWN BY: JDV | CHECKED BY: | APPROVED BY:

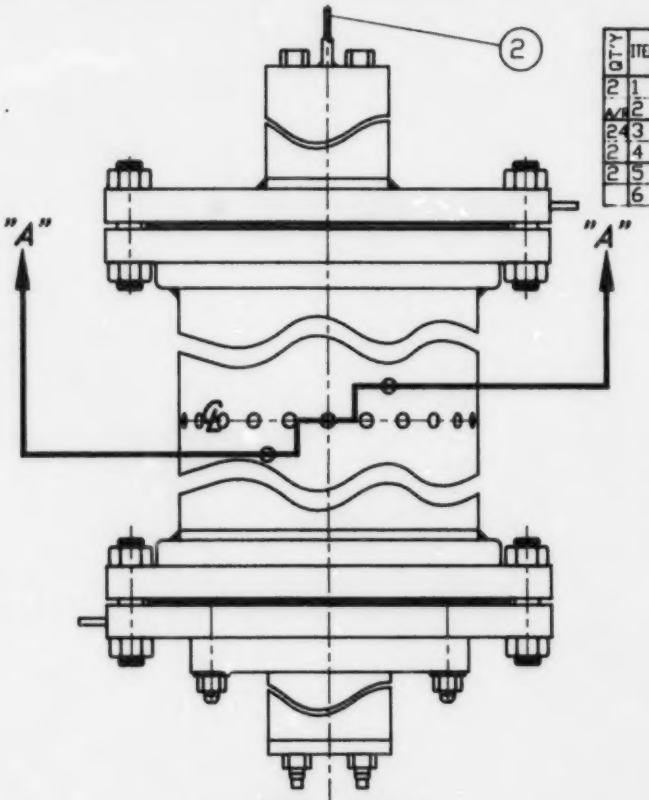
ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

0.	±0.75(0.030)
1.0	±0.25(0.010)
0.00	±0.13(0.005)
ANGLES	1°
CORNERS INSIDE	-0.25(0.010)
CORNERS OUTSIDE	-0.50(0.020)

063B018



CROSS SECT "A-A"



TOP VIEW

QTY	ITEM	DESCRIPTION	IDENTIFICATION
2	1	QUARTZ FIBER	
AR	2	TUBING: 3/16"x0.035" THK WALL, S STL	
2	3	T/C ASS'Y	
2	4	RETAINING SLEEVE	IT3-063B017
2	5	LVDT HOUSING	IT2-063B017
	6		

SHOP ORDER NO.

REVISION	
1	
2	

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STERN LABORATORIES INC.

TITLE: CANDU PRESSURE TUBE BALLOONING INSTRUMENTATION ASS'Y

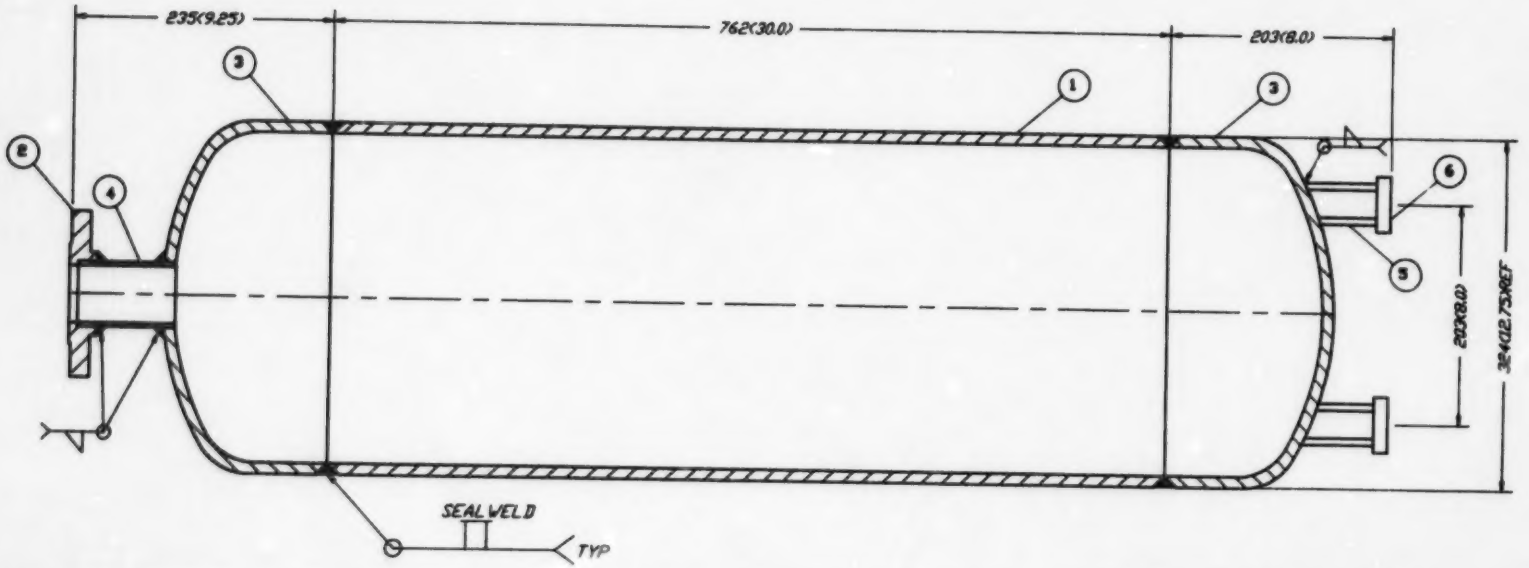
SCALE: | DRAWN BY: | CHECKED BY: | APPROVED BY:

ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

0.	±0.7(0.030)
±0.0	±0.25(0.010)
0.00	±0.13(0.005)
ANGLES	°
CORNERS INSIDE	-0.25(0.010)
CORNERS OUTSIDE	-0.05(0.015)

063B019

QTY	PC	DESCRIPTION	MATERIAL
1	1	[illegible]	[illegible]
2	1	[illegible]	[illegible]
3	1	[illegible]	[illegible]
4	1	[illegible]	[illegible]
5	1	[illegible]	[illegible]
6	1	[illegible]	[illegible]



1	SHOP ORDER NO.		
2	REVISION		

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STERN LABORATORIES INC.

TITLE: CANDU PRESSURE TUBE BALLOONING PRESSURE SUPPRESSION TANK

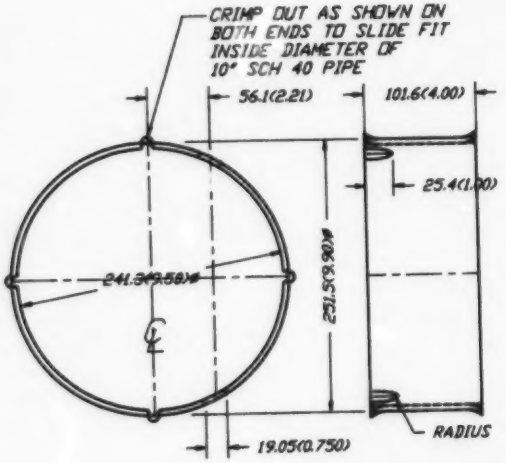
SCALE: | DRAWN BY: Mark Fisher | CHECKED BY: | APPROVED BY:

ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

DECIMALS
X ±0.76(0.030)
XX ±0.38(0.015)
0.00 ±0.13(0.005)
ANGLES ±1°
CORNERS INSIDE -0.38(0.015)
CORNERS OUTSIDE -0.38(0.015)

063B020

QTY	ITEM	DESCRIPTION	IDENTIFICATION
	1	FROM 5mm THK S STL SHEET	



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STERN LABORATORIES INC.

TITLE: CANDU PRESSURE TUBE BALLOONING THERMAL REFLECTOR DETAIL

SCALE: | DRAWN BY: S.M./2015/12 | CHECKED BY: | APPROVED BY:

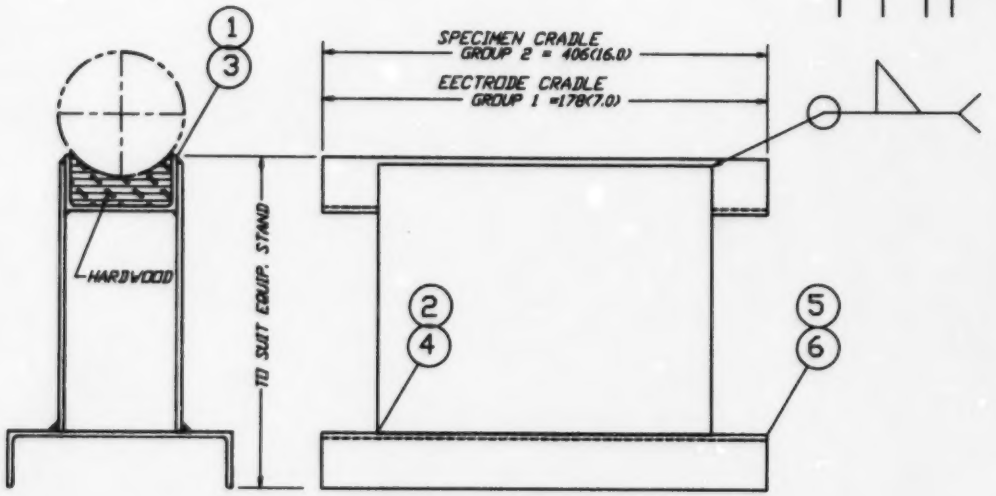
ALL DIMENSIONS IN MILLIMETERS (INCHES)
SURFACE FINISH ALL OVER
TOLERANCES UNLESS OTHERWISE NOTED
ROUNDNESS,FLATNESS,PARALLELISM,CONCENTRICITY,AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

DECIMALS
0. ±0.7(0.030)
0.0 ±0.25(0.010)
0.00 ±0.13(0.005)
ANGLES 1°
CORNERS INSIDE -0.25(0.010)
CORNERS OUTSIDE -0.4(0.015)

063B021

NO.	REVISION	SHOP ORDER NO.
1		
2		

GROUP 2	GROUP 1	ITEM	DESCRIPTION	IDENTIFICATION
	1	1	ALUM CHANNEL -C 4x5.4 - 7'LG	
	2	2	ALUMINUM PLATE	
1		3	ALUM CHANNEL -C 4x5.4 - 16'LG	
2		4	ALUMINUM PLATE	
	1	5	ALUM CHANNEL -C 8x11.5 - 7'LG	
1		5	ALUM CHANNEL -C 8x11.5 - 16'LG	



SHOP ORDER NO.

REVISION

1 2

STERN LABORATORIES INC.

TITLE: CANDU PRESSURE TUBE BALLOONING CRADLE ASSEMBBLIES

SCALE:

ALL DIMENSIONS IN MILLIMETERS (INCHES)

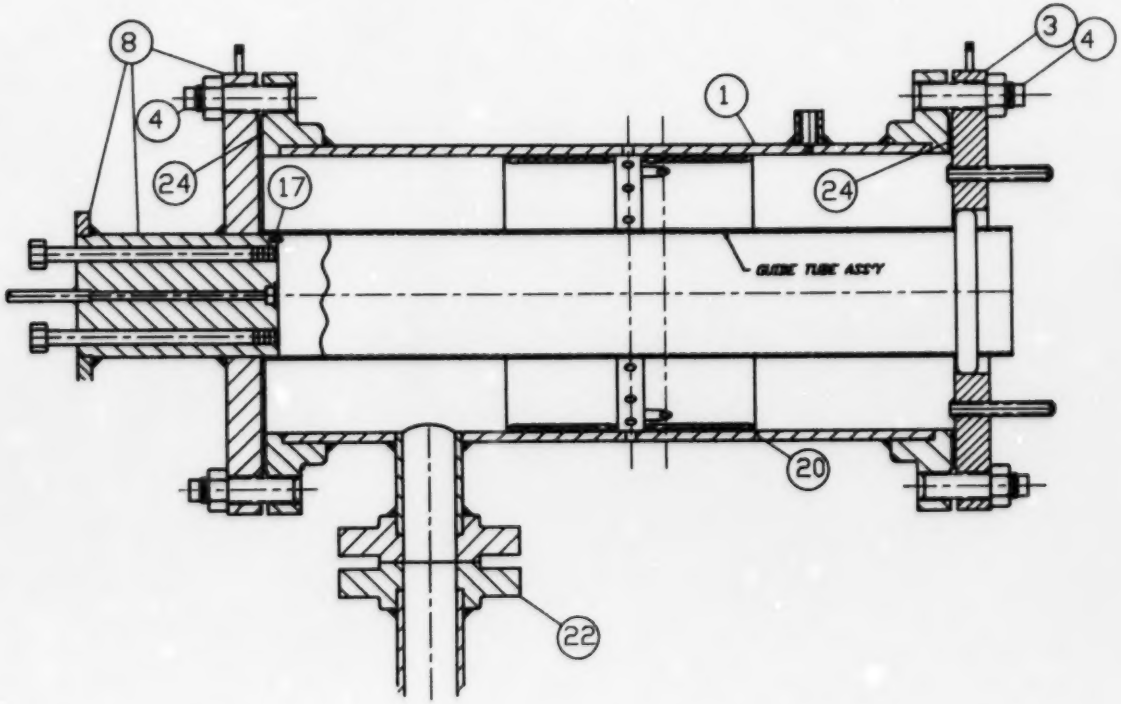
SURFACE FINISH ALL OVER ✓ ✓

TOLERANCES UNLESS OTHTERWISE NOTED

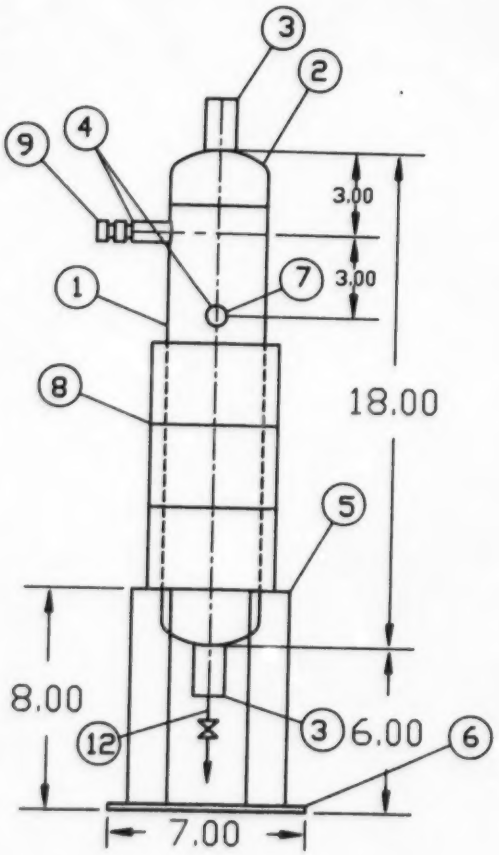
SQUARENESS,FLATNESS,PARALLELISM,CONCENTRICITY,AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES

0 ±0.75(0.030)
0.0 ±0.25(0.010)
0.00 ±0.13(0.005)
ANGLES
CORNERS INSIDE-0.25(0.010)

063B022



STERN	TITLE: DANBU PRESSURE TUBE BALLOONING GENERAL ASS'Y	
SCALE: 1/2		0638023



NOTE	QT'Y	ITEM	DESCRIPTION
	1	1	PIPE: 3" SCH 80 SA-106 GR B SMLS
	2	2	CAP: 3" SCH 80 B W C STL SA-105
	2	3	1/2" NPT COUPLING 3000# SA-105
	2	4	1/4" NPT COUPLING 3000#
	2	5	LEGS: L2x2x1/4"
	2	6	FOOT PLATE: 7"x7"x1/4"THK
	1	7	1/8"x1/4" NPT SWAGELOK MALE CONNECTOR FOR 1/8" TYPE "K" T/C STNLS STL SHEATH
	3	8	WATLOW THINCAST BAND HEATER 3"x3.5"I.D. 240V 1000W
	1	9	SWAGELOK: 3/8"x1/4"NPT MALE CONNECTOR
*	1	10	MONITROLLER: ANALOGDIC # AN25C02-2-1-X-1-P-X-X-K-C-X
*	1	11	RELAY: POTTER & BRUMFIELD "PRD5AY0" 120V,SPDT,25A
	1	12	3/8" DRAIN LINE

NOTE: *=NOT SHOWN

DESIGN DATA

OPERATING CONDITIONS _____ PSIG AT _____
SHELL DESIGN CONDITIONS 150 PSIG AT 650°F
TUBE DESIGN CONDITIONS _____ PSIG AT _____
SPECIFIED CORROSION ALLOWANCE _____
STRESS RELIEF _____ CODE STAMP _____
SHELL SPEC. _____ RADIOGRAPH _____
HEAD SPEC. _____ JOINT EFF. _____
HYDROSTATIC TEST SPEC. _____ PSIG THRUS. F TEST WT. _____
SHIPPING WT. _____ CAPACITY _____
REMARKS _____

FABRICATING DATA

WELDING SPEC: STAINLESS STEEL _____
CARBON STEEL _____
CLEANING SPEC. _____
RADIOGRAPH INSPECTION _____ DYE PENETRATIONSPEC. _____
ULTRASONICSPEC. _____
MATERIALS SPEC. (unless otherwise specified)

	STAINLESS STEEL	CARBON STEEL
PIPE		
TUBE		
FITTINGS		
PLATE		

SUPPLEMENTARY TESTING _____

ALL DIMENSIONS IN INCHES [MILLIMETERS]

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STERN LABORATORIES INC.

TITLE: CANDU PRESSURE TUBE BALLOONING STEAM PRESSURIZER

SCALE: 1=4 | DRAWN BY: [illegible] NOV/15/77 | CHECKED BY: | APPROVED BY:

TOLERANCES UNLESS OTHERWISE NOTED
CORNERS INSIDE-0.8(0.8)
CORNERS OUTSIDE-4.0(0.4)
ANGLES ±1°
SURFACE FINISH ALL OVER ✓✓
SQUARENESS, FLATNESS, PARALLELISM, CONCENTRICITY, AND TRUE POSITION TO BE WITHIN THE LINEAR TOLERANCES
FRACTIONS ±
DECIMALS –
.X( ) ±0.8(0.75)
.XX( ) ±0.12(0.25)
.XXX( ) ±0.025(0.13)

063B024

SHOP ORDER NO.	REVISION
1	2

APPENDIX A

EFFECT OF WALL THINNING ON HEAT FLUX WITH JOULE HEATING

EFFECT OF WALL THINNING ON HEAT FLUX WITH DIRECT (JOULE) HEATING

According to Ohm's law, $V = IR$ (1)

where V is the potential difference
I is the current and
R is the resistance

The energy E dissipated due to the current is

$$E = VI \quad (2)$$

hence, from (1) $E = V^2R^{-1}$ (3)
or
$$E = I^2R \quad (4)$$

With resistors in parallel, all resistors experience a common potential difference, therefore equation (3) will give the power dissipated in each. For resistors in series, the identical current has to flow through all, therefore equation (4) must be applied to give the power dissipated.

If ballooning occurs only over a part of the perimeter (case I), the circumferential heat flux profile is an inverse function of the local R. However, if a ballooning pressure tube balloons uniformly around the whole perimeter at any location (case II), this would constitute a situation of resistors in series. Therefore the axial, cross-section average heat flux profile is a direct function of the axial resistance profile.

In both cases, because the wall has thinned, the local resistance has increased, i.e., if the wall thickness is w, $R \propto w^{-1}$ (assuming the diameter to thickness ratio is large). Therefore in case I, the local heat flux would change as a direct function of wall thickness, i.e., it would fall upon thinning, and in case II it would change as an inverse function of wall thickness, i.e., the local heat flux would increase (assuming that the total power is maintained by increasing the voltage). Therefore, if the heat flux is $\emptyset$,

for case I $\emptyset \propto w$ (approx.) (5)

and for case II $\emptyset \propto w^{-1}$ (approx.) (6)

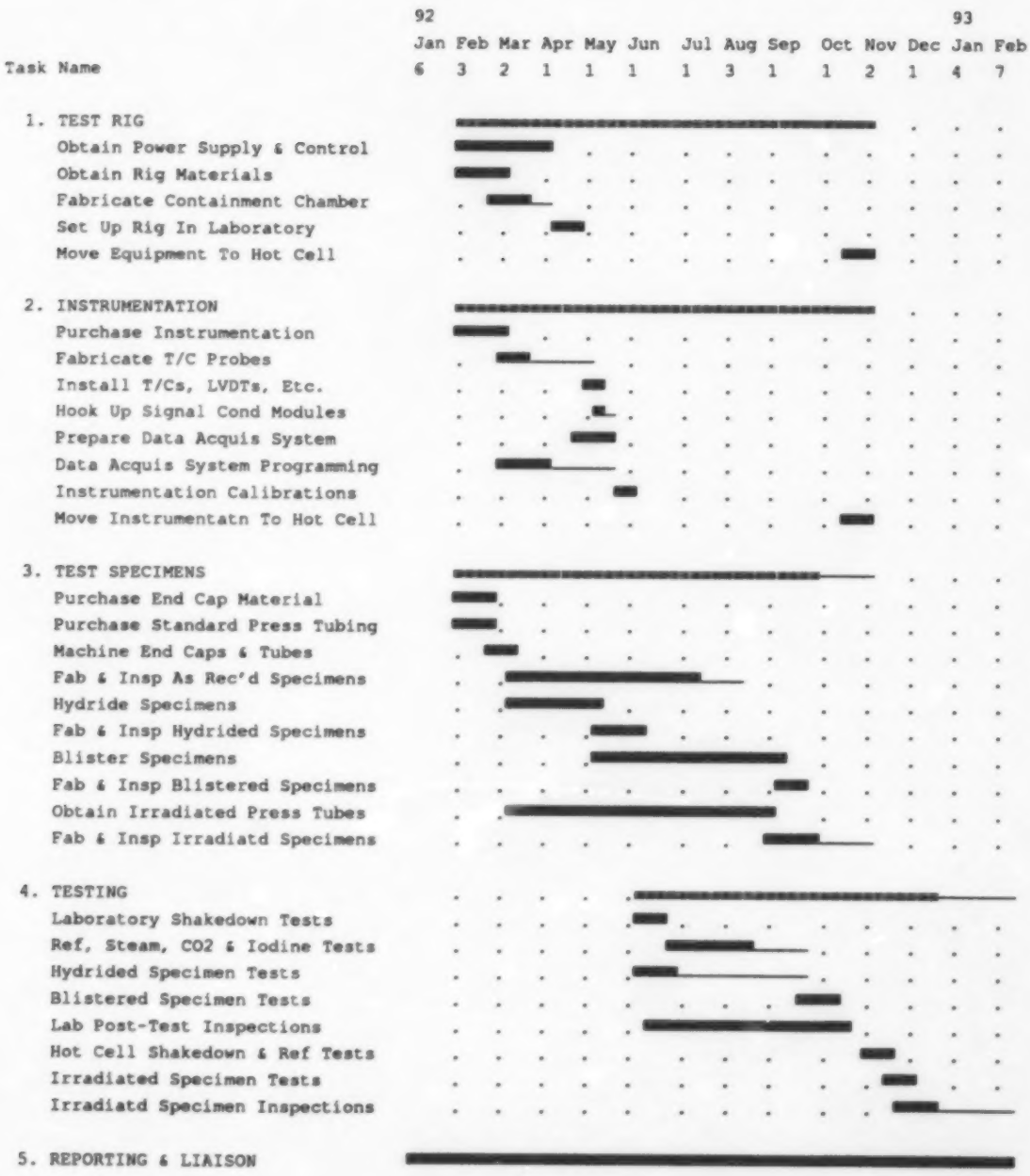
In real life, there is some evidence that both cases take place during ballooning (see, for example, Figure 11 in Reference 3). The effects for the two cases therefore tend to offset each other at the location of the "balloon".

APPENDIX B

WORK PLAN FOR PHASE 3

TABLE B1

PHASE 3 WORK PLAN


92
93
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb
6 3 2 1 1 1 1 3 1 1 2 1 4 7
Task Name
1. TEST RIG
Obtain Power Supply & Control
Obtain Rig Materials
Fabricate Containment Chamber
Set Up Rig In Laboratory
Move Equipment To Hot Cell
2. INSTRUMENTATION
Purchase Instrumentation
Fabricate T/C Probes
Install T/Cs, LVDTs, Etc.
Hook Up Signal Cond Modules
Prepare Data Acquis System
Data Acquis System Programming
Instrumentation Calibrations
Move Instrumentatn To Hot Cell
3. TEST SPECIMENS
Purchase End Cap Material
Purchase Standard Press Tubing
Machine End Caps & Tubes
Fab & Insp As Rec'd Specimens
Hydride Specimens
Fab & Insp Hydrided Specimens
Blister Specimens
Fab & Insp Blistered Specimens
Obtain Irradiated Press Tubes
Fab & Insp Irradiatd Specimens
4. TESTING
Laboratory Shakedown Tests
Ref, Steam, CO2 & Iodine Tests
Hydrided Specimen Tests
Blistered Specimen Tests
Lab Post-Test Inspections
Hot Cell Shakedown & Ref Tests
Irradiated Specimen Tests
Irradiatd Specimen Inspections
5. REPORTING & LIAISON

APPENDIX C

IRRADIATED PRESSURE TUBE SOURCING

Prospective contractors should contact the following to procure irradiated pressure tube sections, cut into 0.5 m lengths:

Ontario Hydro Retubing Projects
700 University Avenue,
Toronto, Ontario M5G 1X6

Attention: Mr. Sean Burke Phone 592-4325

The details are provided in the attached letter.

JAN 2 1 1991

ontario hydro

700 University Avenue, Toronto, Ontario M5G 1X6

January 11, 1991

To: Frank Stern
Stern Laboratories
1590 Burlington Street E
Hamilton, ON
L8H 3L3

Subject: COST OF PROCUREMENT OF IRRADIATED TUBING SECTIONS

Dear Frank:

As you requested, I have obtained an estimate of the cost of procuring four 0.5m sections of irradiated pressure tubing.

After investigating several possibilities, I have determined that the best method would be to obtain the specimens from twenty-four full pressure tubes being removed from Pickering Unit 4 for Shield Code confirmation testing.

These tubes are tentatively scheduled for removal from Pickering to Chalk River Nuclear Research Laboratories in the spring of 1992. The cost to you would be the cutting of the specimens at Chalk River and their transport to Whiteshell Nuclear Research Laboratories in Manitoba. This entire process was unofficially estimated by Chalk River staff at not more than $50,000, and taking no more than two weeks.

This estimate is dependent on you advising Ontario Hydro of your requirements early enough to identify satisfactory pressure tubes for removal. It is understood that you need one specimen from each of four separate pressure tubes, each having experienced in excess of 1 MeV and 10^{26} neutrons/m^2. By copy of this letter, M. Natesan (H10 B07 ext.2876) of the Nuclear Engineering Department has been advised of these requirements.

I trust that this meets with your approval. Should you have any further question please feel free to contact me.

Regards,

Sean Burke
H18-C18 ext.4325
Retube Engineering Department
In-Service Nuclear Projects

c.c. M. Natesan H10 B07
E.J. Bennett H18 A17
L.W. Woodhead A08 H01

APPENDIX D

CANADIAN HOT CELL FACILITIES

The five hot cell facilities with capabilities sufficient to carry out the irradiated specimen tests, as provided by the AECB, are listed in Table A2. Of these, Nordian International Inc, who operate facilities in Kanata, Ontario and the TRIUMF facility at UBC, are not interested in doing this work, or in providing hot cell space at this time due to isotope production demands. However, the may be interested at a future date. AECL Research, who operate hot cells at their Chalk River and Whiteshell Laboratories, have decided that the latter facilities would be more suitable, and have provided cell rental and skilled manpower rates, as given in Table A2. A positive response has also been received from McMaster University. Letters, confirming the above, are provided at the end of this Appendix.

Being familiar with both of the above facilities, we believe that both could provide a suitable hot cell and specimen handling facilities. AECL Research has a competent staff of experienced engineers and technicians, and could handle all aspects of the work. McMaster University has only a small experienced staff and therefore the contractor would be required to carry out all of the work not specifically related to the handling of the specimens. The rental and manpower costs of the latter facility, however, are much lower, as shown in Table A2.

McMASTER UNIVERSITY
NUCLEAR REACTOR

1280 Main Street West
Hamilton, Ontario L8S 4K1
Telephone: (416) 525-9140
Telex: 061-8347 EXT. 3270
FAX 416-528-5030

Stern Laboratories
1590 Burlington Street East
Hamilton, Ontario
L8H 3L3

Attention: C.F. Forrest, Vice-President

January 16, 1991

Dear Mr. Forrest:

With regard to your letter of November 08, 1990, we would be pleased to participate in the pressure tube ballooning test program. Our staff and Hot Cell Facility are available for handling irradiated specimens, and we have 50 kVA power capacity as discussed previously. We are not equipped to handle the sample preparations; we do not have the remote cutting and welding capability which you require.

Our rates are as follows:

Hot Cell Rental	$60.00	per day or part thereof
Technical Staff	$49.50	per hour "
Professional Staff	$73.70	per hour "

These rates are valid until March 31, 1991. After that date, you may assume a five percent increase for budgetary purposes.

If you require further information, please call me at 525-9140, extension 3270.

Sincerely yours,

Michael Butler

Michael P. Butler
Chief Reactor Supervisor

NORDION INTERNATIONAL INC.

1990 November 30 File: P-0

Mr. C.F. Forrest
Vice-President
Stern Laboratories Inc.
1590 Burlington Street East
Hamilton, Ontario
L8H 3L3

Dear Sir:

BALOONING OF CANDU PRESSURE TUBES
DSS PO #87055-0-4015/01, STERN LABS REFERENCE SL63

After careful consideration, we at Nordion International Inc. have decided not to quote on the work involving the Ballooning of CANDU pressure tubes. Although the project description is very interesting and our hot cell facilities are suitable for this requirement, we are unable to interrupt our ongoing source production.

Once you have a firm schedule and time requirement for hot cell work, please feel free to give me a call and I will re-examine our work load. If, at that time, we can interrupt source production, I would be willing to quote for use of our hot cell facilities and cell operators.

Thank you for considering Nordion International Inc. for this project.

Yours sincerely,

J.L. Norton, P.Eng.
Manager
Cobalt Operations
Industrial Irradiation Division

:cg

cc: P.A. Gray
G.M. Defalco

447 March Road, P.O. Box 13500, Kanata, Ontario, Canada K2K 1X8 Tel.: (613) 592-2790 Telex: (053) 4162 Fax: (613) 592-6937
447 chemin March, C.P. 13500, Kanata, Ontario, Canada K2K 1X8 Tél.: (613) 592-2790 Télex: (053) 4162 Fax: (613) 592-6937

AECL EACL

AECL Research
Whiteshell Laboratories
Pinawa Manitoba
Canada R0E 1L0
(204) 753-2311
Fax (204) 753-8404
Telex 083-671345

EACL Recherche
Laboratoires de Whiteshell
Pinawa (Manitoba)
Canada R0E 1L0
(204) 753-2311
Fax (204) 753-8404
Télex 083-671345

MAR-90-80
1990 November 19

Mr. C. F. Forrest
Stern Laboratories Inc.
1590 Burlington Street, East
Hamilton, ON
L8H 3L3

Dear Mr. Forrest:

BALLOONING OF CANDU PRESSURE TUBES
DSS P.O. #87055-0-4015/01, STERN LABS REF. SL63

I have spoken to our Shielded Facilities Section Head regarding your request for hot cell facilities and skilled labour to conduct the test program referenced above. Both he and the Operations Branch Head have expressed an interest in conducting this work. The Whiteshell Laboratories Shielded Facilities staff has had considerable experience in similar work, and if present trends continue, hot cell space and skilled labour should be available when required.

The presentation of a firm cost estimate will require considerably more discussion between you and Len Woodvorth, however for your preliminary information, our commercial rates are $100/hour/workstation for hot cells, and $77/hour for skilled technical labour. These rates are effective until March 31, 1991. For programs such as this, there are numerous other cost considerations such as shipping, decontamination, storage and disposition of the irradiated material after testing, etc.

I have enclosed a brochure on our Shielded Facilities and other related material for your information.

Sincerely,

M. A. Ryz
Manager, Commercial Office
Reactor Development - WL

enc.

c: L.G. Woodvorth

AECL EACL

AECL Research
Chalk River Laboratories
Chalk River Ontario
Canada K0J 1J0
Tel (613) 584-3311
Fax (613) 584-4024
Telex 053-34555

EACL Recherche
Laboratoires de Chalk River
Chalk River (Ontario)
Canada K0J 1J0
Tél (613) 584-3311
Fax (613) 584-4024
Telex 053-34555

REACTOR DEVELOPMENT
Commercial Office

1990 November 22

Dr. C.F. Forrest
Vice-President
Stern Laboratories Inc
1590 Burlington Street East
Hamilton, Ontario
L8H 3L3

Dear Dr. Forrest:

BALLOONING OF CANDU PRESSURE TUBES
DSS PO # 87055-0-4015/01, STERN LABS REF. SL63

Thank you for your letter dated 1990 November 08 and the attached proposal. After consultation with my colleagues at the Whiteshell Laboratories it has been decided that our hot cells at Whiteshell are best equipped to perform the necessary work. Since Whiteshell are prepared to respond to your proposal, and since it is not Research Company policy to have Chalk River and Whiteshell knowingly compete for the same work, Chalk River will not be responding to your proposal at this time.

Thank you for giving us the opportunity to bid.

Yours truly,

M.D. Watson

MDW:g
Encl.
c. B.A. Cheadle
M.A. Ryz
N. Smith

TABLE DI
CANADIAN HOT CELL FACILITIES

FACILITY	CONTACT	HOT CELL RENTAL $ per hr	PROFESSIONAL LABOUR $ per hr	TECHNICAL LABOUR $ per hr	COMMENTS
Atomic Energy Of Canada Ltd. Chalk River, Ontario K0J 1J0	M.D. Watson Reactor Development Commercial Office	-	-	-	Declined to participate.
Atomic Energy Of Canada Ltd. Pinawa, Manitoba R0E 1L0	M.A. Ryz, Manager Commercial Office Reactor Development - WL	100.00	-	77.00	
Nordion International Inc. 447 March Road, P.O. Box 13500, Kanata, Ont. K2K 1X8	J.L. Norton, Manager Cobalt Operations Industrial Irradiation Division	-	-	-	Declined to participate.
TRIUMF Facility Operated by Nordion Intl. (See Above)		-	-	-	Declined to participate.
McMaster University 1280 Main Street West Hamilton, Ont. L8S 4K1	M.P. Butler Chief Reactor Supervisor Nuclear Reactor	7.50 (8 hr day)	73.70	49.50	